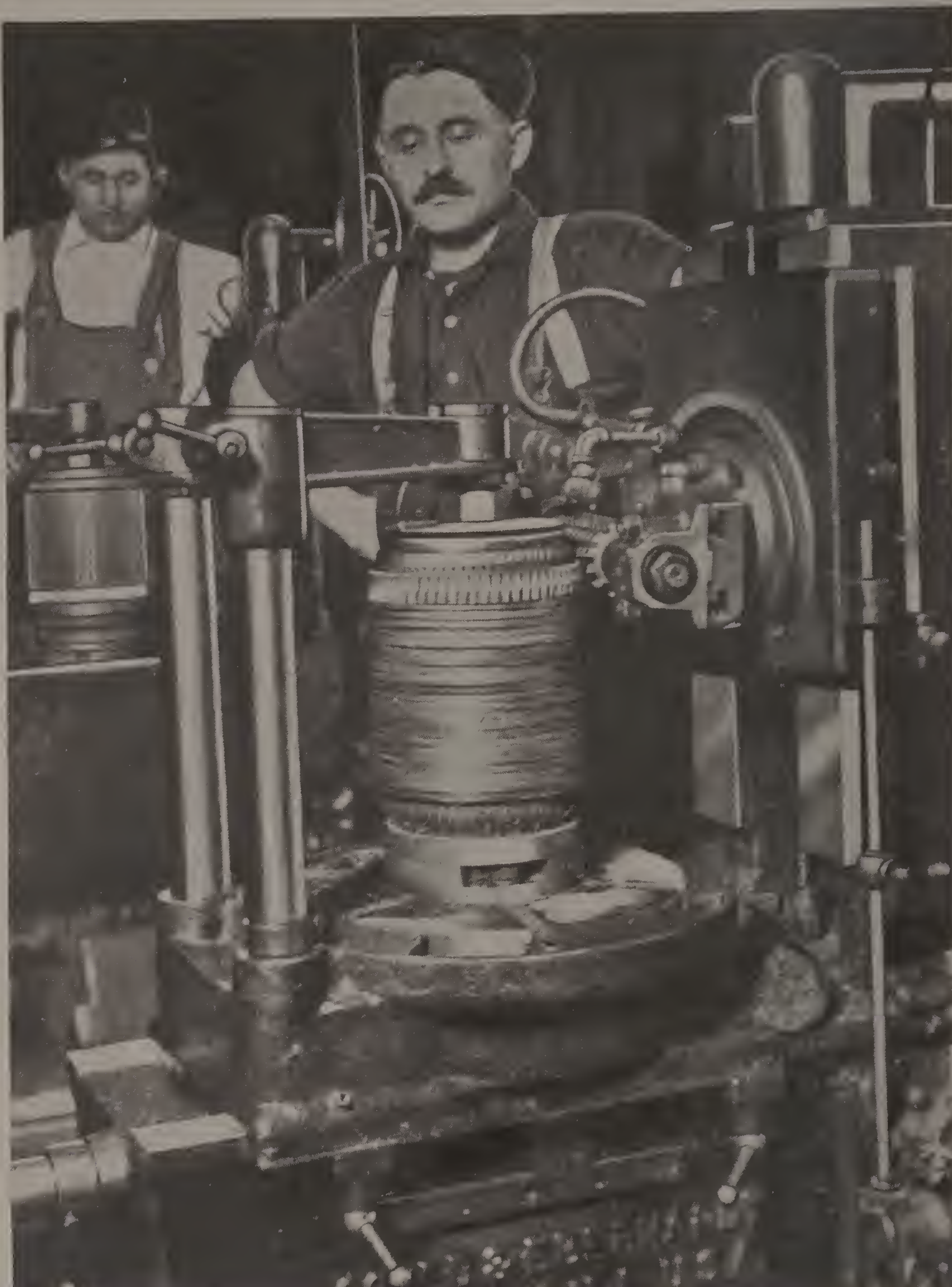

CUTTING SPROCKETS WITH MULTIPLE-SPINDLE GEAR HOBBER
Courtesy of Gould and Eberhardt, Newark, New Jersey

Modern Shop Practice

A General Reference Work on

MACHINE SHOP PRACTICE AND MANAGEMENT, PRODUCTION MANUFACTURING, METALLURGY, WELDING, TOOL MAKING, TOOL DESIGN, DIE MAKING AND METAL STAMPING, FOUNDRY WORK, FORGING, PATTERN MAKING, MECHANICAL AND MACHINE DRAWING, ETC.

Editor-in-Chief

HOWARD MONROE RAYMOND, B. S.
Dean of Engineering, Armour Institute of Technology

Assisted by a Corps of

MECHANICAL ENGINEERS, DESIGNERS, AND SPECIALISTS IN SHOP METHODS AND MANAGEMENT

Illustrated with over Two Thousand Engravings

SIX VOLUMES

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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost manufacturers and engineering firms, in making these volumes thoroughly representative of the best and latest practice in machine and pattern shops, foundries, and drafting rooms, and in the construction and operation of machine tools, and other classes of modern machinery; also for the valuable drawings and data, suggestions, criticisms, and other courtesies.

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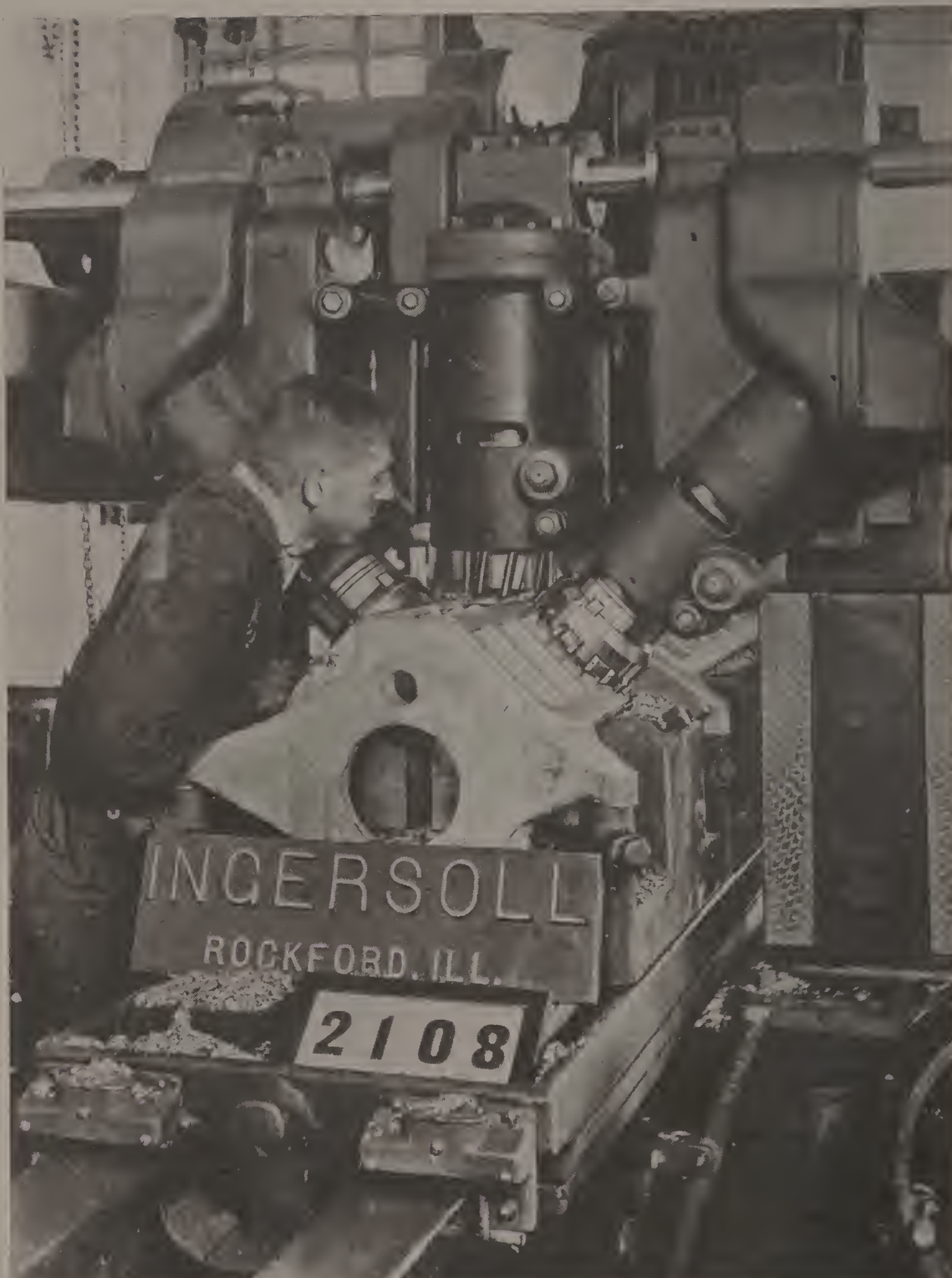

MACHINING EIGHT-CYLINDER ALUMINUM CRANK CASES
The outer spindles are set at 45 degrees and the center spindle takes care of the top cut.
Courtesy of Ingersoll Milling Machine Company, Rockford, Illinois

Foreword

A LITTLE more than a century ago our mechanical development had its beginning when the first prime movers were invented and developed. With the development of machines came the development of mechanics to run these machines, to fabricate the parts and assemble them into the finished articles. The evolution of both machines and mechanics has been marvelous, the accuracy of workmanship of today being easily two hundred times that of a century ago, and the speed of manufacture probably much more than this. Since that time one industry has helped to develop others until today the mines produce ore in large quantities to supply the iron, copper, and other metals; the great steel mills supply the raw or fabricated material; the foundries and forging shops fashion the many castings and forgings for the intricate machine to be built; the immense shops machine the parts and assemble them for the market. Everywhere we turn we find a manufactured article which has gone through these various changes from raw material to finished product.

¶ "Production" methods have enormously increased the output of our shops and the machines which have made this development possible are of a diversified character—speed lathes, planers, multiple drillers, grinders, milling machines, stamping machines, die presses and the jigs, tools and dies which go with them—all of these have contributed to the accuracy and speed of manufacture. The demands of the automobile industry have done wonders in hastening this development as the manufacture of the parts in duplicate was absolutely necessary in order to cheapen the price of the assembled machines. The fact that many of the present-day automobiles

are shipped "knocked down" to assembly points without ever having been put together is an eloquent testimonial to the accuracy with which the duplicate parts are built. Another contributing factor in modern production methods is the development of high speed steels which enable the operators to run the machines at speeds hitherto unattainable.

¶ And yet with all this wonderful development of the machines themselves and the design of what are termed "automatics," the workman has not lost his skill. In fact, one trip to a well-organized scientific machine shop will teach any skeptic that the intelligent workman who has contributed so largely to the mechanical developments of the past twenty years is more skilled, more intelligent, certainly better paid, and more interested in his work than ever.

¶ But this same skilled mechanic is today a specialist. He has no opportunity to build a complete machine or even a small part of one; his active work is carried on along rather narrow lines. Consequently, it is all the more necessary for him to have a standard reference work to help him in other shop lines with which he is unfamiliar. "Modern Shop Practice" is such a work—one which has been tested through six editions—and the practical treatises on the various shop subjects have been supplied by well-known teachers and practical men and are strictly up-to-date. The authors have at all times kept in mind the practical nature of their subjects and numerous shop kinks and other helpful suggestions have been introduced. It is the hope of the publishers that this new edition will supply the needs of both the skilled mechanic and the layman who is interested in mechanical affairs.

¶ In conclusion, grateful acknowledgment is given to the authors and collaborators — engineers and designers of wide practical experience and teachers of recognized ability—without whose co-operation this work would have been impossible.

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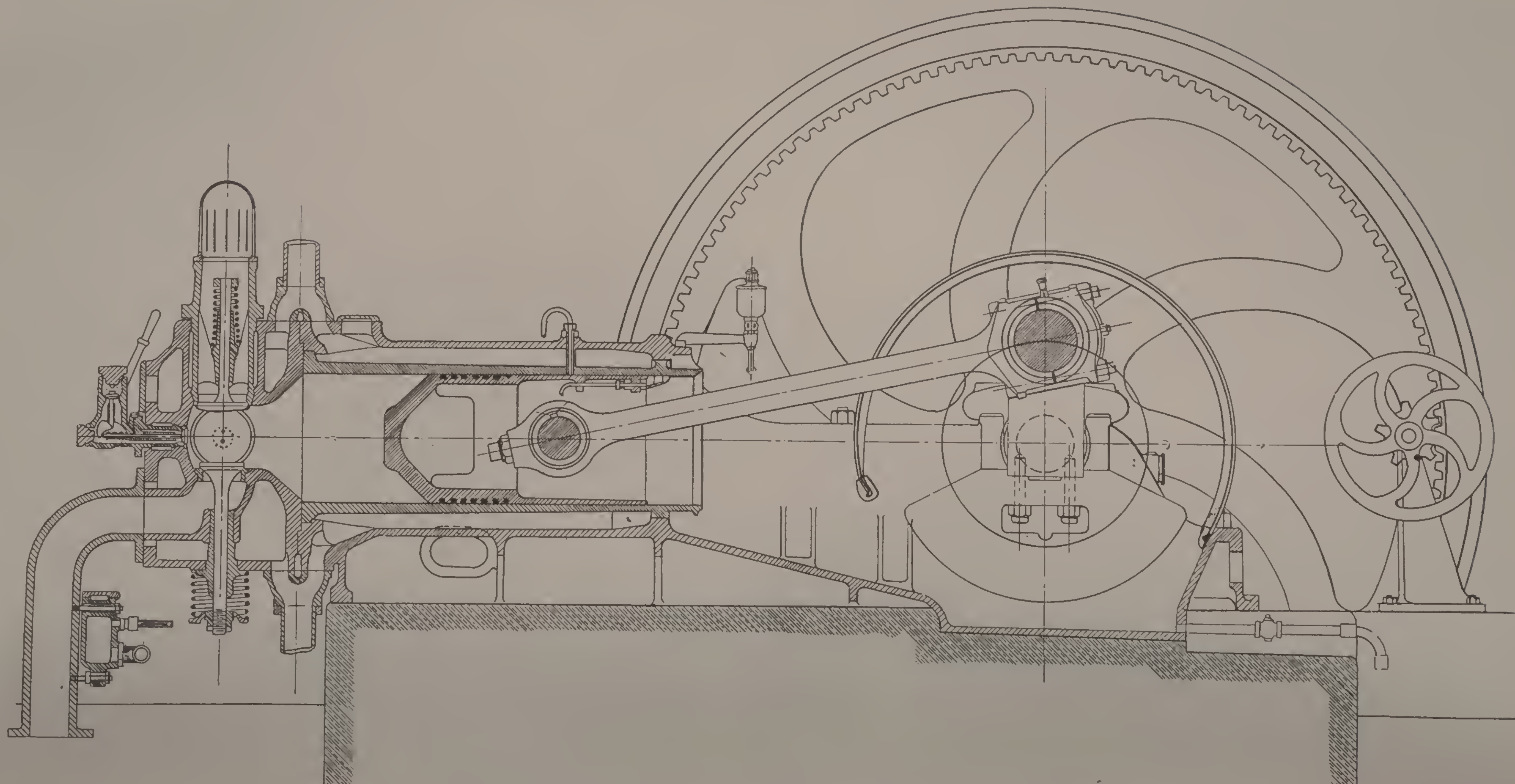
† For professional standing of authors, see list of Authors and Collaborators at front of volume.



SECTIONAL ELEVATION OF NEW CROSSLEY OIL ENGINE

Courtesy of Crossley Brothers, Manchester, England

MACHINE DRAWING

PART I

WORKING DRAWINGS

METHODS AND CONVENTIONS

In Mechanical Drawing, Parts I, II, and III, the common drafting instruments and materials are described, and hints given regarding their use; the fundamental geometrical problems are solved; the principles of orthographic projection are stated, and their application to intersections and developments illustrated. A careful study of these Parts, with the actual drawing work incident thereto, should have given the student considerable facility in producing good line work; he should now be able to draw neatly and accurately any simple piece which may be given him, correctly applying the principles as described.

In producing working drawings the principles already laid down are constantly used, and the more they are at the finger ends of the student the easier his work will become. The principles of projection must be thoroughly understood and fixed in the student's mind in order that he may devote himself with the greatest application to the actual detail of the drawing, and he must not be compelled at every step to turn back to find out how to make the simple projections.

Definition of Working Drawings. A working drawing is a drawing which completely instructs the workman, so that he is able actually to make in the shop the object which the drawing represents; in other words, a working drawing conveys to the mechanic all the information necessary to make the object. The student should constantly keep before him the idea that the workman must take a drawing, and, without any further instructions verbal or written, produce the object as the draftsman intended it to be made. The instruction supplied by the drawing should not only cover the form and size of the object, but also the kind of material of which it is to be made, the number of pieces desired, and the

finish of its surfaces. A drawing, therefore, is a sort of abbreviated language, or shorthand method of conveying an amount of exact, detail information, which it would take many pages of manuscript to convey.

A second point to be noted in connection with a working drawing is that the workman has no time to puzzle over a mass of lines and figures more complicated than necessary. This means that special attention must be paid to making the drawing as simple as possible; all lines and figures which are unnecessary, beyond the point of conveying complete information, are hindrances rather than helps to the workman; moreover, it takes the draftsman's time to make these extra lines and figures, and thus the drawing

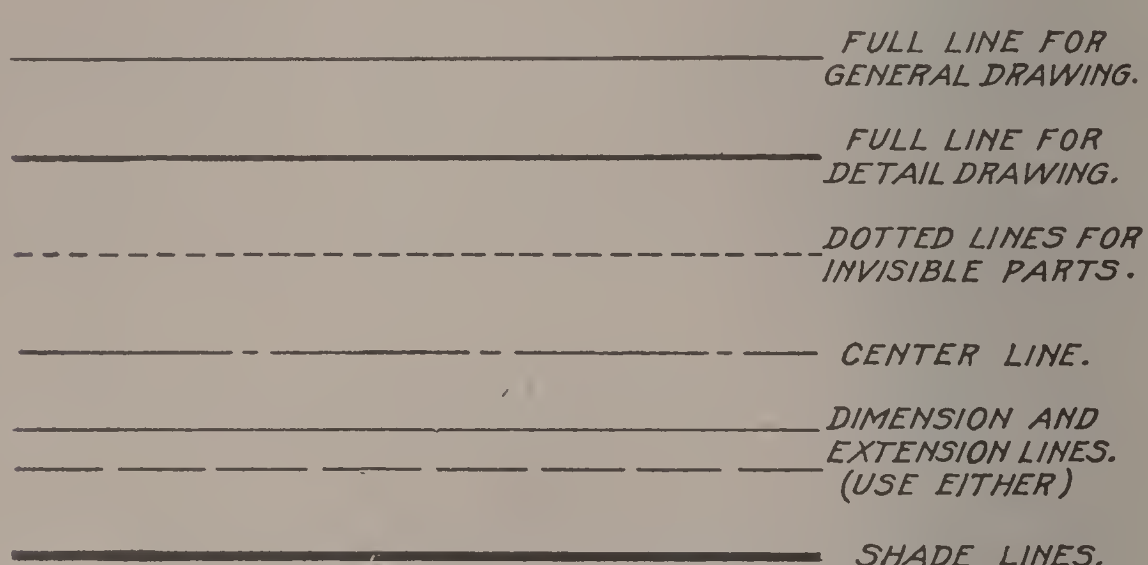


Fig. 1. Conventional Lines Used in Machine Drawings

becomes unnecessarily expensive. A good drawing, therefore, not only implies *accuracy and completeness* but also *simplicity and directness.*

Lines. The secret of a clear drawing, as far as the line work is concerned, lies not only in absolute uniformity in the making of the lines, but in choosing certain characteristic lines to convey different ideas. The most common kinds of lines used are shown in Fig. 1 and described below, and the purposes of their use are stated.

Full Lines. Full lines represent the portions of the object which are visible; they should be bold and clear, heavy on detail drawings, say $\frac{1}{32}''$ wide, and lighter on an assembled drawing.

Invisible Lines. Invisible lines represent the hidden parts of the object; they consist of short dashes regularly spaced, the spaces

being about $\frac{1}{4}$ the length of the dash; the dashes should never have a greater width than that of the full line, and usually should be slightly less. A drawing is much easier to read if the full lines force themselves on the eye, while the dotted lines, by their lighter character, are left in the background.

Center or Axis Lines. Center or axis lines consist of alternate long and short dashes, finer than the main lines of the drawing.

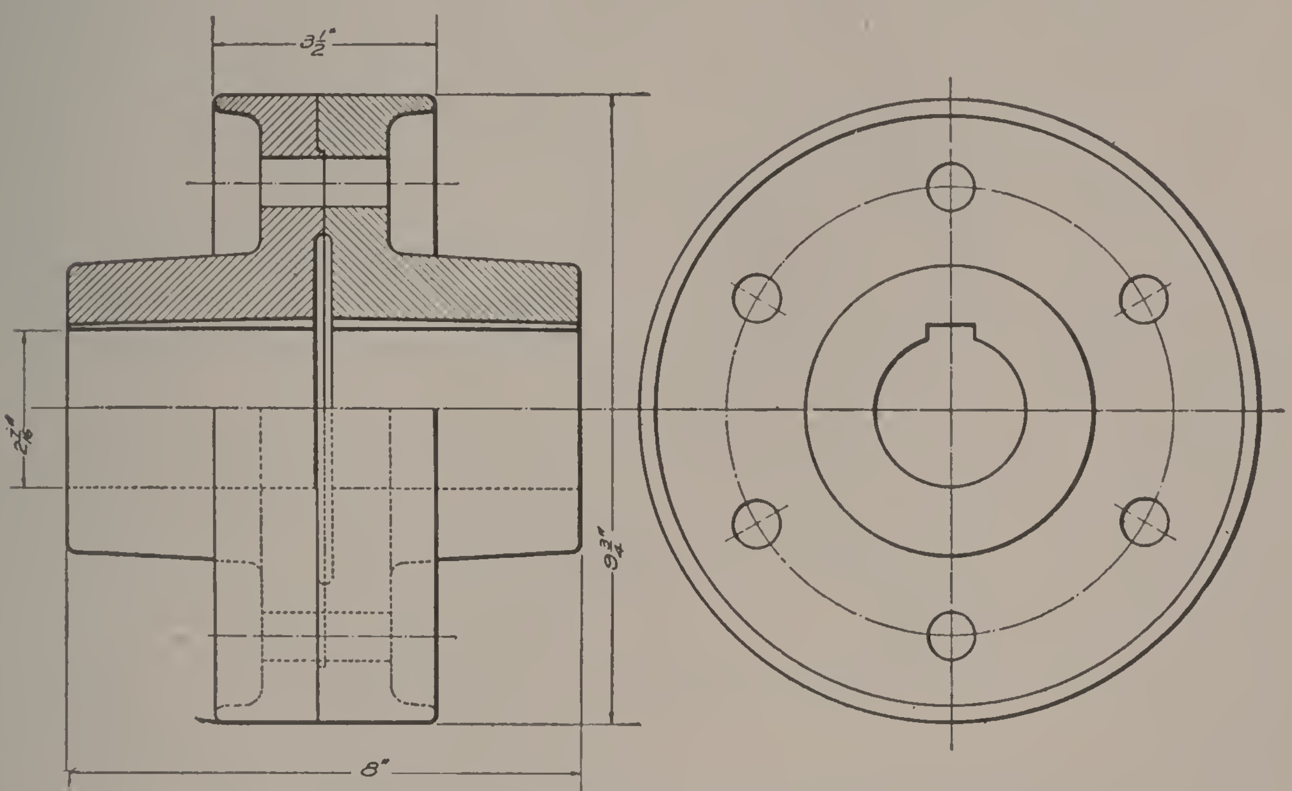


Fig. 2. Flanged Coupling Giving Practical Application of Fig. 1

Some draftsmen prefer not to use "dash and dot" center lines, but make them continuous fine lines. Either style is good.

Dimension and Extension Lines. Dimension and extension lines are made fine, like center lines, and may be either full or dotted, according to the preference of the draftsman; the full line is preferable on account of its bolder character and the shorter time it takes to make it.

Extension lines start a short distance away from the edges of the object, so as to break up the continuity of the lines of the object and the extension line.

Dimension lines are run between the extension lines, terminating at the extension lines in arrows. The extension lines should always run a short distance beyond the point at which the dimension line touches them.

Shade Lines. Shade lines are used for the purpose of more clearly bringing out to the eye the projecting edges of the object on the shadow side, and should be the heaviest lines on the drawing; the proper effect is secured if these lines are made nearly twice as heavy as the principal lines of the drawing.

Fig. 2 shows a flanged coupling in which the lines given in Fig. 1 are applied to an actual problem. In the lower half of the elevation observe how the invisible parts are shown by dotted lines.

Arrangement of Views. Imagine a rectangular block placed within a glass box, and the surfaces projected to the top, front and right-hand side, as in Fig. 3; now open the box in the manner indicated in Fig. 4 and we have three views of the object on a plane surface, *i.e.*, the drawing paper of the draftsman. These views are called top plan, front, and side elevations respectively, and are denoted in the figure by the letters *T*, *F*, and *S*. If more views are required, the arrangement is shown in Fig. 5. The bottom plan *B* is found below the front elevation, and the left side elevation *S′* is found on the left of the front elevation, the same principles of projection being used as in the former case.

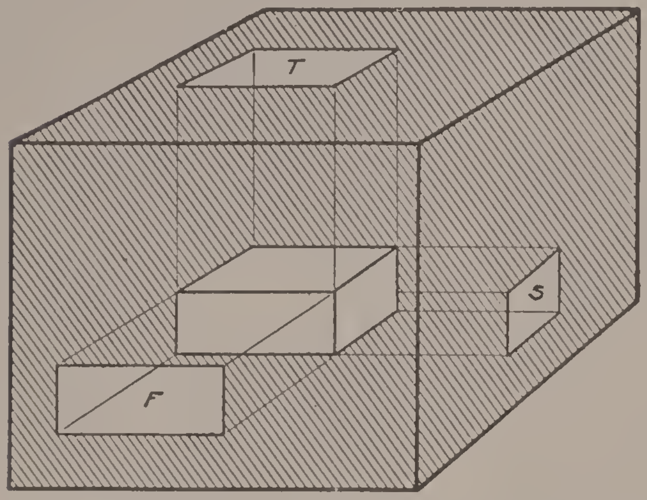


Fig. 3. Rectangular Block Within a Glass Box, the Surfaces Projected to the Top, Front, and Right-Hand Side

The above procedure is equivalent to tracing on each side of the box the outline of the object as observed by the eye, when directly in front of each side of the object; after this is done the unfolding of the box results in the outlines shown in Fig. 4.

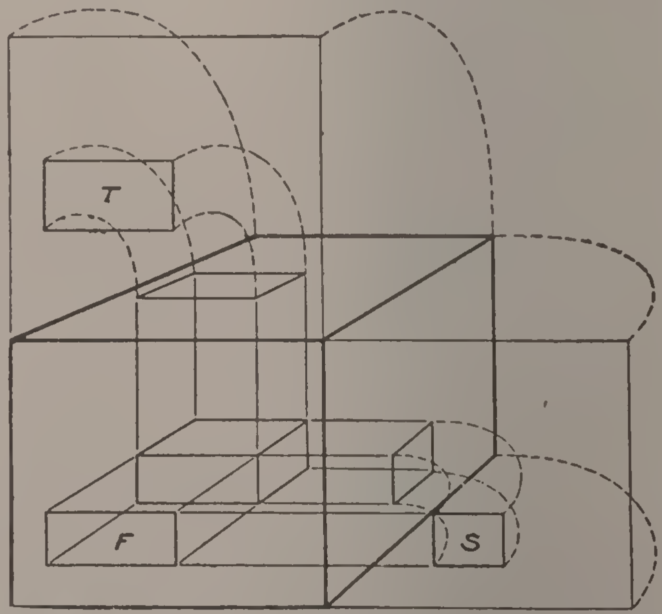


Fig. 4. First and Preferred Method of Showing Top, Front, and Right-Hand Side Views of a Rectangular Block on a Plane Surface

If we consider the front elevation of the object as our starting point, then the *top plan* is *above*, the *bottom plan below*, the view of the *right-hand side* is on the

right of, and the view of the *left-hand side* is on the *left* of the front elevation. This arrangement of views is easily remembered and is very logical; it is the most common method of projection in drafting work, and will be used throughout this book. For such a simple object as that considered above, two views only are necessary, a front elevation and top plan, but machine drawings frequently require three views, top, front, and side, and sometimes more.

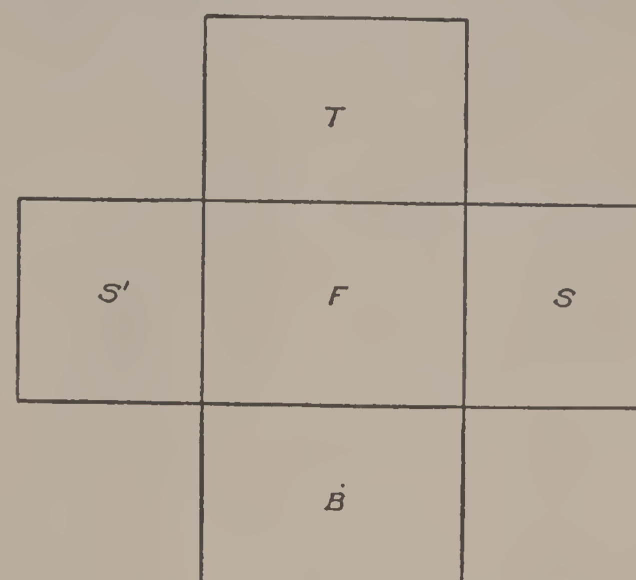


Fig. 5. Method of Showing Five Views of a Rectangular Block on a Plane Surface

Some draftsmen prefer the method of projection shown in Fig. 6, by which the lines of the object, instead of being observed through an imaginary glass partition and traced thereon, are projected away from the eye upon surfaces *beyond* the object; the surfaces are then unfolded as before, with the result, as shown in Fig. 7, that the front elevation, being the starting point, the *top plan* is *below*, the *bottom plan* is *above*, the *left-hand* view is at the *right* of, and the *right-hand* view is at the *left* of the front elevation. This system of projection has few advantages for machine drawing, and has been largely superseded by the former method.

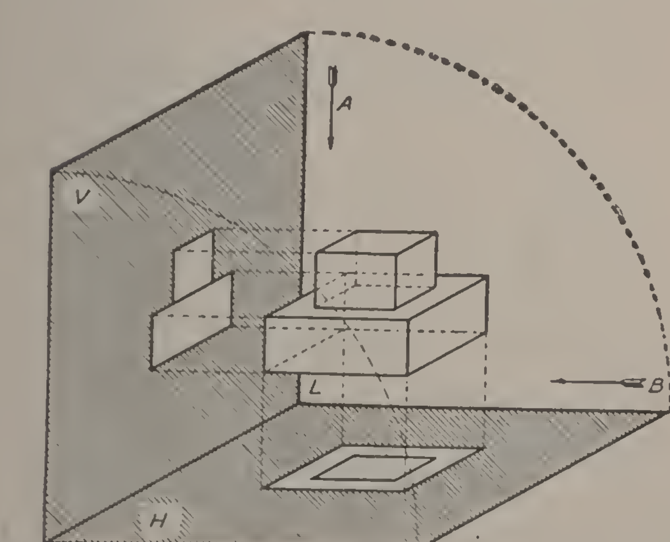


Fig. 6. Second Method of Showing an Object and Its Projections in Vertical and Horizontal Planes

(*Not Advised for Machine Drawing*)

Sectional Views. The interior construction of machine parts, especially if at all complicated, can seldom be clearly or completely shown by dotted lines. A large number of dotted lines on a drawing is very confusing, and in many cases renders the drawing useless. Sectional views are used to overcome this difficulty, and as an unlimited number of sections can be taken, it is always possible to make clear the interior construction of any piece, however complicated.

Crosshatching. To make a sectional view, the object is supposed to be cut open, and all the material removed between the cutting plane and the eye. This makes visible the hidden portion, and the drawing, therefore, consists of full lines made the same as any other, except that the material which was cut by the plane is "crosshatched". Crosshatching consists of drawing medium width lines, regularly spaced, across the cut surface, the lines usually being at an angle of 45° with the horizontal. In case of two adjoining surfaces being cut, the lines are sloped to the right and left, respectively.

The butt joint given in Fig. 8 shows the use of crosshatching when the section taken is through different pieces of the same material. Notice the different angles at which the section lines are drawn for each separate piece.

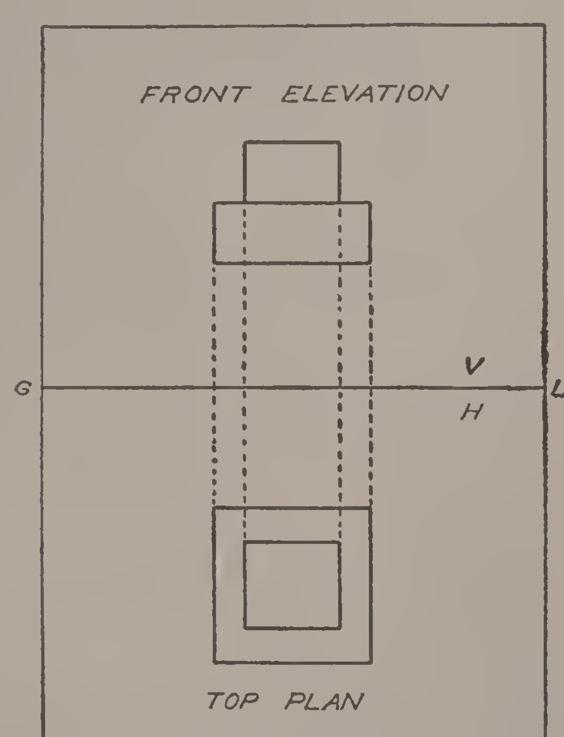


Fig. 7. Second Method of Projection, Planes Unfolding
(*Not Advised for Machine Drawing*)

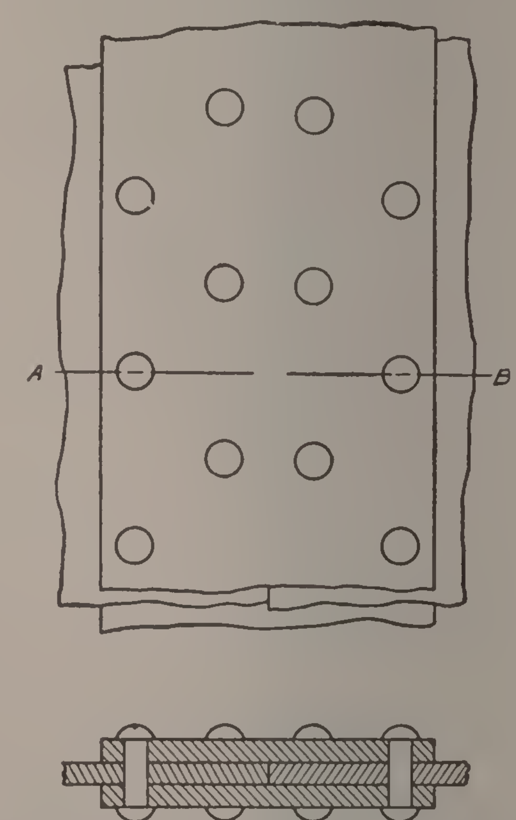


Fig. 8. Butt Joint Showing Use of Crosshatching When Section Is Through Different Pieces of One Material

It is often convenient to show the kind of material of the object by the style of crosshatching. The conventional styles generally used are illustrated in Fig. 9. It is quite general, however, to use the plain form (as for cast iron), and call for the material by a specific note, thus leaving no possible doubt of the material required, and simplifying the labor of crosshatching, which is a tedious process at best. The distance between the lines should be as wide as possible,

to save labor, and yet bring out the surface clearly. A good average spacing is about $\frac{3}{32}''$. Fig. 10 shows the end of a connecting rod. The section shows the different materials of which the object is made, cast iron, brass, steel, and babbitt.

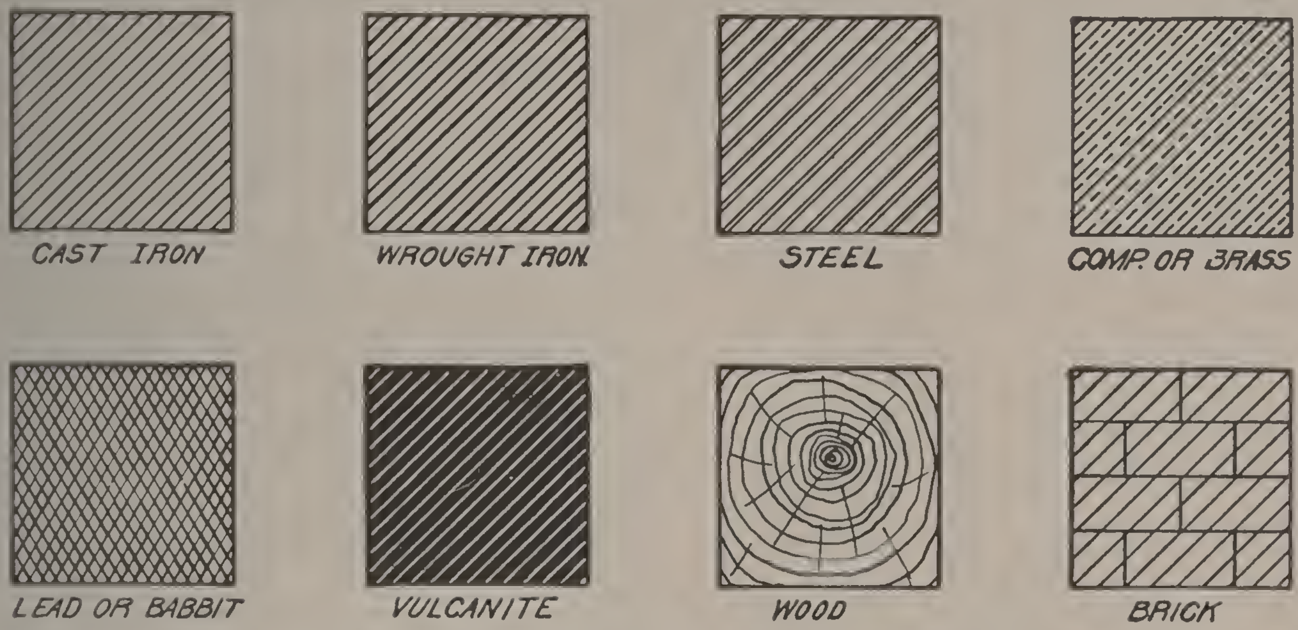


Fig. 9. Conventional Representation of Materials

Shade Lines. The theoretical principles for shade lines, already given in Mechanical Drawing, Part III, cannot be exactly applied to working machine drawings without involving an excessive amount of time and labor. The conventional rule, therefore, has been

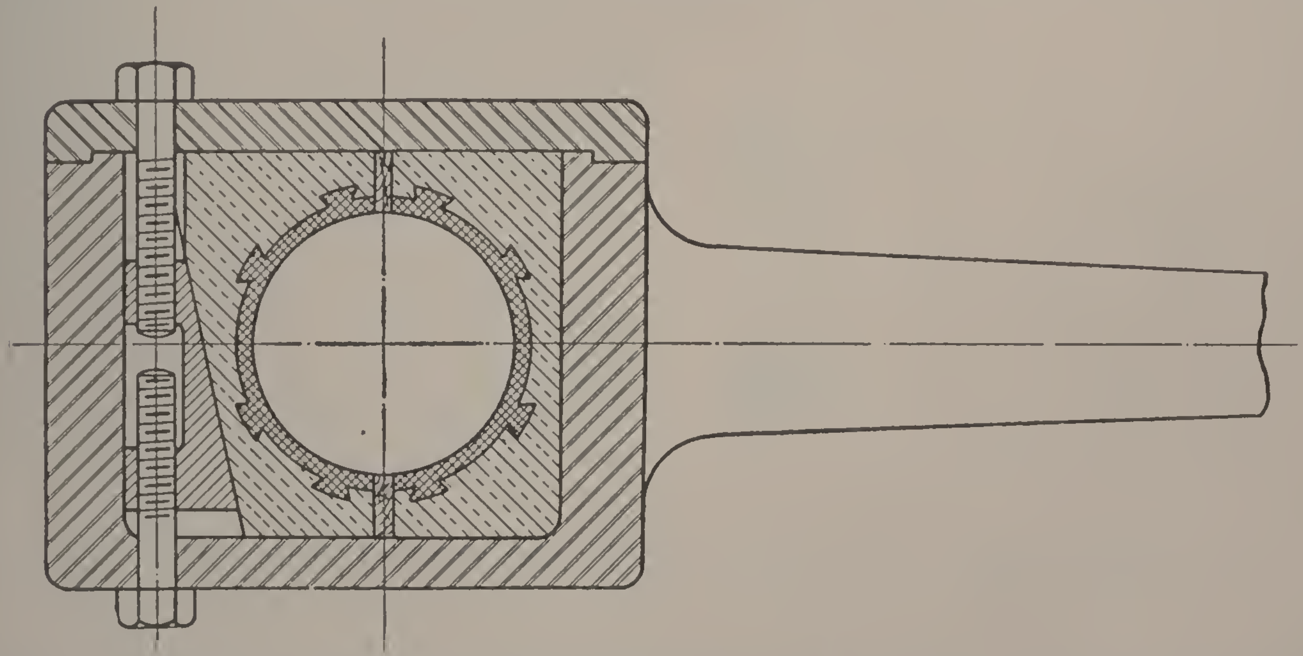


Fig. 10. End of Connecting Rod Showing Crosshatching When Section Is Through Different Materials

established that *shade lines may be used for all lower and right-hand projecting edges.* By "projecting edges" are meant edges of surfaces which are not flush with adjoining surfaces, but which project above them, or are in a plane nearer the eye. All views of an object are

treated alike, the ray of light casting the shadow being supposed to come from the upper left-hand corner of the drawing. The contour lines of cylinders, cones, and other rounded surfaces, *if projecting*, are shaded the same as sharp edges.

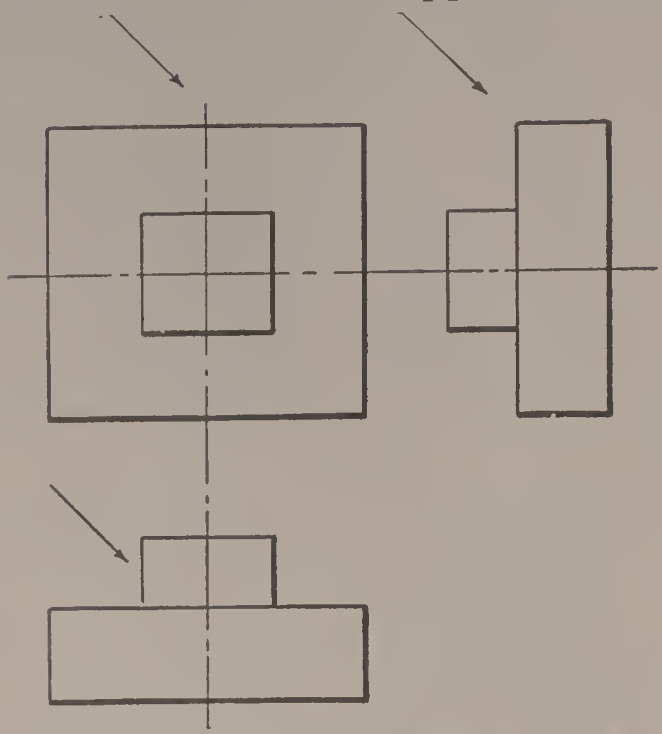


Fig. 11. Direction of Light Rays and Location of Shade Lines

Uses. Shade lines, when used, are for the specific purpose of relieving the flatness of drawing, and represent a purely conventional means of indicating to the eye projecting surfaces, *i.e.*, surfaces which are in different planes parallel to the eye. Whether the surfaces be curved or flat, as long as they are projecting, or in front of other surfaces, is of no moment, for the effect desired is the same for both, namely, the separation of the surfaces.

Applications in Practical Work. Few drawing offices allow shade lines to be used on regular detail machine work on account of the extra labor required and the loss of accuracy in the drawing by the use of a wide line. For general or "show" drawings, where the effect of separating the surfaces is desired, thus bringing out more clearly the relation of the parts, the use of shade lines is occasionally permitted. The draftsman should know how to apply them when required, and Figs. 11 to 16 illustrate their use.

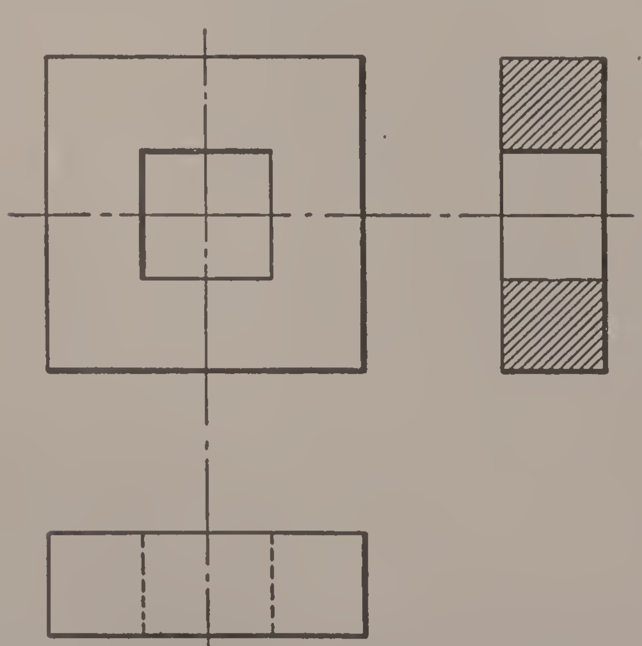


Fig. 12. Location of Shade Lines for Piece with Hole

Shade-Line Methods. Fig. 11 shows the assumed direction of the ray of light in each of the three views. The piece should be inked in with the usual standard width of line, then gone over the second time, making the extra width for the shaded lines on the *inside* of the proper lines. This leaves the outside measurement of the piece unchanged for possible

scaling. Some draftsmen claim that they can make the heavy shade lines as they go along, thus avoiding the second inking, but in the long run it will be found that time will be saved, more uniform lines and fewer blots made, if the process of shading be accomplished by a second inking.

Fig. 12 is similar to Fig. 11 but with a hole instead of a lug, and the difference in shade lines should be noted.

Fig. 13 is the same as Fig. 11 with a round boss and the lower right-hand corner rounded.

Fig. 14 is a plain washer, Fig. 15 a common hexagonal nut.

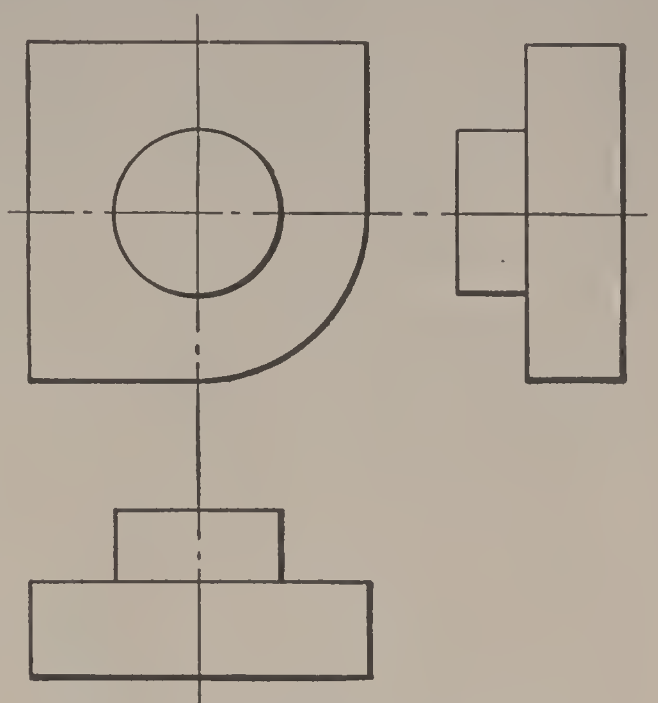


Fig. 13. Location of Shade Lines for Rounded Corner

Fig. 16 is a washer or disk with a shaft in it. The right- and left-hand views are shown to bring out the point that the shaft projecting on the right has its end shaded, while on the left, being flush with the face of the disk, it is not shaded.

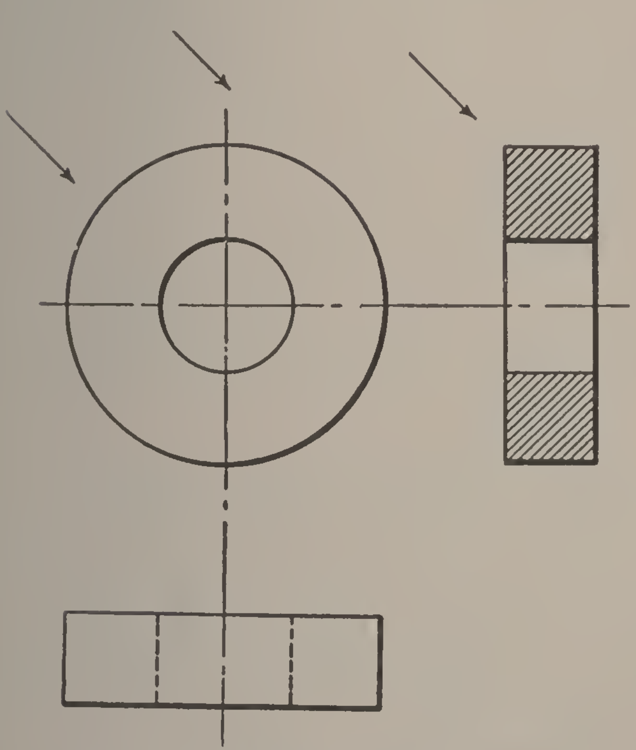


Fig. 14. Location of Shade Lines for Circular Piece

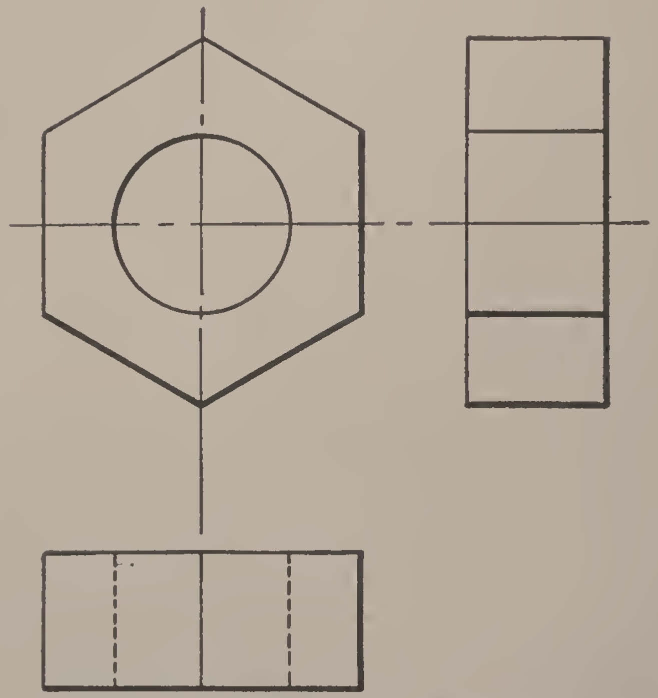


Fig. 15. Location of Shade Lines for Hexagonal Piece

Dimensions. It is easy to spoil an otherwise good drawing by loose and careless methods of putting on dimensions. Systematic and careful effort must constantly be used to make every dimension

upon a drawing absolutely clear. To put it still more strongly, it must be absolutely impossible for any dimension of a drawing to raise doubt in the workman's mind as to its meaning. The draftsman has no justifiable excuse for mistakes in the shop due to poorly made dimension lines or small and blotted figures.

The arrows terminating the dimension lines should be pointed, bold, and regular, thus, |← $3\frac{1}{2}''$ →|, not like this, |← $3\frac{1}{2}''$ →|. The arrow points should exactly touch the extension lines, thus, |← $5\frac{1}{4}''$ →|, not like this, |← $5\frac{1}{4}''$ →|. The figures should be broad, bold, and clear, and of good size to be easily read. A gap may be left for the figure, thus, |← $3\frac{5}{8}''$ →|, or the line may run straight

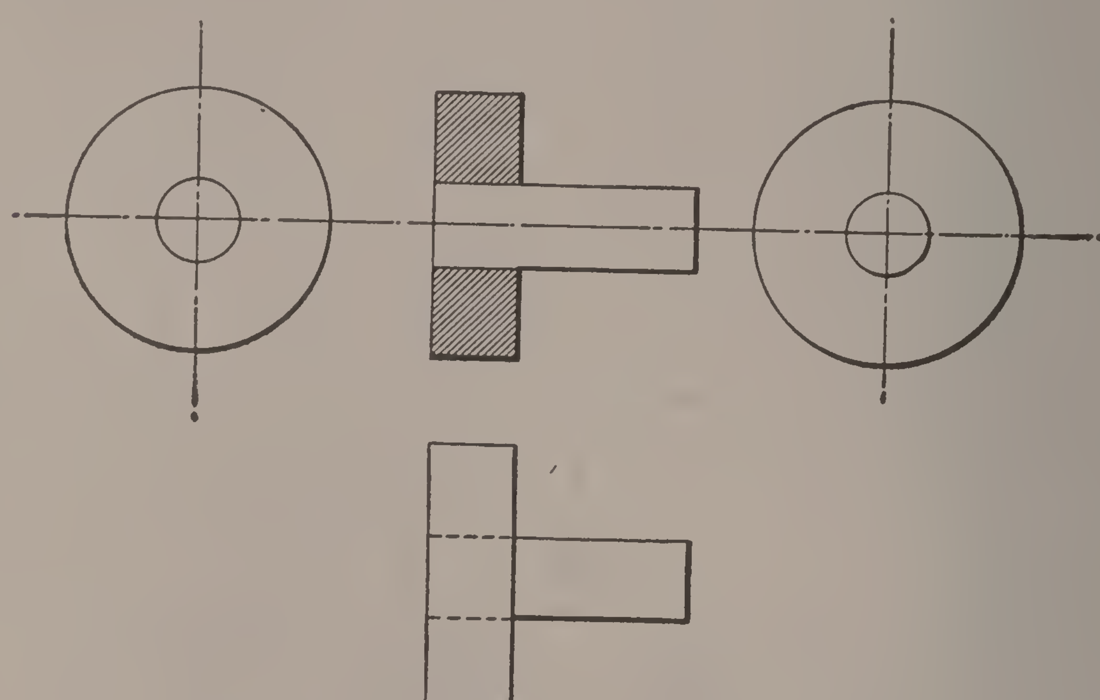


Fig. 16. Location of Shade Lines for Disk with Shaft

through, thus, |← $3\frac{5}{8}''$ →|, or the figures may be placed wholly above the line thus, $3\frac{5}{8}''$ |← →|.

It should be noted that by making figures broad, they will appear bold and clear, even when they are limited to small height. The common error of making them narrow destroys their bold character, and renders them difficult to read. Note the difference between the following examples, both sets of figures being exactly the same height, but one broad and the other narrow, FIG 25 FIG.25.

Fractions should always have the dividing line horizontal, thus, |← $\frac{11}{16}''$ →| not like this, |← 11/16″ →|.

Small dimensions, or dimensions in cramped places should be made thus, →| |← $\frac{3}{16}''$ or →|← $\frac{1}{8}''$ or →| $\frac{1}{8}''$ |←.

For distances greater than 36 inches, and often for distances greater than 12 inches, the dimensions are usually given in feet and inches. These dimensions should be indicated thus, |←4'-6"→|, the dash being made bold and conspicuous.

COMPLETE INSTRUCTIONS AND SPECIFICATIONS

It is naturally difficult for the student to determine what constitutes "complete instructions to the workman", and this knowledge can only be *fully* acquired by experience, both in drawing room and shop. Association, however, with the shop men who use drawings, a careful observation of their operation of tools, and a general familiarity with handling of material in a shop, help wonderfully in getting the right point of view and proper spirit for making a good drawing. When one stops to think about it, to give instructions without having the least idea of how the workman will go about it to follow them, seems the height of foolishness, yet that is what the student who tries to make working drawings wholly from book rules is doing. He should use his book knowledge as a guide and constant help, but he should be a "shop man" *first, last, and all the time.* When he has acquired the habit of constantly putting himself in the workman's place, his drawings will be right and will convey "complete instructions to the workman."

Classes of Workmen Using Drawings. In the ordinary run of shop work there are several classes of workmen who have to use drawings. Broadly classed, they are as follows:

Pattern makers, Blacksmiths, Machinists (including Toolmakers, Special Machine men, and Erectors), Order and Receiving Clerks.

These several workmen will use the same drawing, and the instruction which it conveys must be so arranged that each can readily pick out the portion which he needs to enable his work to be properly done. The general requirements of each are discussed below and form the basis for the style and methods of dimensioning drawings used in common practice, and illustrated in this book.

Pattern Maker. The pattern maker, on receiving a detail drawing of a piece, first proceeds to copy it full size, divided up into such sections as are convenient, upon his work board. This board

is merely a large smooth table top, set up on a couple of horses. Sometimes brown paper is tacked on this board and the pattern drawing made on it, but more often the pencil lines are made directly on the surface of the board and the board resurfaced for future work. He does not make a finished drawing, but with his straight-edge, large dividers, and compasses he lays out enough to enable him to see and measure the detail at all points.

This pattern layout is made for a number of reasons. Molten cast iron, when it cools, shrinks about $\frac{1}{8}''$ per foot, so the pattern has to be made larger than the figures on the drawing call for. In order to save calculation for each dimension, a "shrink rule" is used, each foot of which is made $12\frac{1}{8}''$ long. The pattern maker uses this rule in all his work, and thus makes his layout on a "shrink" basis.

Wherever the drawing calls for finished surfaces, the stock of the pattern has to be increased by $\frac{1}{8}''$ or more, and this addition has to show on the pattern maker's drawing. In order to get the casting out of the sand of the mold, "draft", or taper on the pattern, has to be allowed. As the draftsman cannot always predict just how the piece will be molded, the "draft" is not shown on the office drawing, and the pattern maker, therefore, has to make the allowance and show it on his drawing. All fillets, sizes of cores and core prints, details of core boxes, and loose pieces of the pattern have to be carefully worked up on the pattern drawing. The result of this special pattern layout often is that certain minor changes have to be made in the shape and size of the piece to permit the pattern to be properly built and readily molded in the foundry, for a good pattern maker has also to be a good foundryman. We thus see that, as far as the pattern maker is concerned, the drawing must be very complete as to detail, both inside and out, and carry dimensions for all surfaces, cores, fillets, corners, etc.

These dimensions must be in even figures as far as possible, as a pattern maker's rule seldom reads finer than $\frac{1}{16}''$. Gear work is a specialty, and decimals are allowable, and there are certain other cases where odd dimensions cannot be avoided. In arranging the dimensions on the drawing, the more knowledge the draftsman has of pattern making, the more conveniently will he figure the drawing for the pattern maker. He will, in figuring the interior of a casting,

think of the core box which will be made, and will be sure that he gives the length, breadth, and depth of the cavity, and all corners, bosses, and lugs projecting into it, with simplicity and clearness. He will give dimensions for all sloping lines and odd-shaped curves definitely and carefully, thinking all the while of the pattern maker and his tools, the square, straight-edge, dividers, and compasses. He will avoid thin edges, and frail projections, and awkward intersections. The consideration of such points as these is what makes a good drawing for the pattern maker to use, and greatly reduces the cost of the pattern, for pattern making is relatively high-priced labor. Some of these points are really points of machine design, but it is not possible for a good detail drawing to be made without using to a small extent, at least, the elementary principles of design. These the student can unconsciously acquire by familiarizing himself with actual shop work.

Blacksmith. The blacksmith sometimes uses a pattern for a forging. This is to enable him to lay aside the drawing for pieces which are to be made in large numbers, and set his calipers quickly and accurately from a pattern. Simplicity of shape is of even more importance to the blacksmith than to the pattern maker. The stock material of the blacksmith consists of straight bars of iron and steel of round, square, and oblong cross section. All bosses, lugs, hubs, or sudden variations of shape have to be produced by "upsetting" or welding, either of which is a process involving time, care, and expense. Forgings, therefore, should be, as far as possible, simple, straight pieces, with few bosses or lugs, and when bends are necessary they should be of the simplest nature.

In forging a piece the blacksmith has to work quickly, and has no time to read or measure fine dimensions, it is therefore useless to expect him to read any finer dimensions than $\frac{1}{16}''$; special attention should be paid to giving him *over-all* dimensions, not only for cutting off the stock, but for enabling him to make his measurements quickly while the piece is hot and gripped by his tongs on the anvil. The blacksmith has to make about the same allowance of extra stock for finished surfaces as the pattern maker.

Machinist. The machinist uses only a few of the figures on the average drawing, while the pattern maker and blacksmith use practically all of them. The machinist is concerned only with finishing

the piece, and views the drawing with regard to the machine work upon it. In order to finish the surfaces accurately in proper relation to one another it is necessary to choose some fundamental face of the piece, first finish that, and then use it as a gauging surface from which to work the others. The draftsman, if he is reasonably familiar with shop work, can usually foresee what this gauging surface will be. This has an important influence on his dimensions, for he should so give the dimensions that the machinist will find them convenient and consistent with all his operations on the piece.

When special tools, jigs, fixtures, and automatic devices are applied for the finishing of pieces in large numbers, the method of dimensioning is apt to be somewhat different from that on the general run of machine work. A free use of notes on the drawing, specifying the nature of finished surface desired, or the kind of fit, or any special points in connection with the machining of the piece, is valuable to the machinist. It is not good economy to spend any more labor on securing a finished surface than the purpose for which it is made requires. For example, in turning up a shaft with a number of bearings along it, most of its surface being free, care should be taken to finish the parts for the bearings to an exact diameter, but for the balance of the length a smooth surface with the diameter reasonably accurate is all that is necessary. The drawing should specify this difference of finish so that the machinist will not waste time on the piece.

The special operations on a piece, such as cutting of gear teeth, grinding and "lapping" of shafts, cutting of threads, etc., are all done subsequent to the main finishing of the piece. For example, the casting for a cut gear is first bored, the hub faced, and the solid rim turned and faced to the dimensions on the drawing. This produces the "gear blank". The subsequent operations of cutting the teeth on an automatic gear-cutting machine, and keyseating the hub on a keyseater, require additional instructions as to the style of cutter, number of teeth, dimensions and style of keyway, etc.

Machine shops are differently equipped for doing the same kinds of work, and this has an important influence on the manner of placing the finishing dimensions on drawings. Thus, some shops have rotary planers instead of the regular reciprocating platen type. Some have turret lathes, screw machines, and horizontal boring

mills, while others have only lathes. Some have grinding machines, both for flat surface and cylindrical work, the final finishing cuts being taken on these machines, after the pieces have been roughed out on the lathe and planer. Grinding machines are now regularly built to take a heavy cut and coarse feed for roughing out the work, thus often dispensing entirely with the lathe. Milling machines, though found in all shops, are used in widely different scopes. Some use the milling machine almost entirely, to the exclusion of the planer, specially heavy machines being adapted for this purpose. Locomotive shops differ in their equipment and practice from stationary engine shops; machine tool and automatic machinery builders have little in common with the equipment of shops for manufacturing heavy power transmission machinery; steam pump shops are wholly different in their equipment from that of an establishment building electrical machinery.

All these differences have an important bearing on the style of drawings needed, and especially so on the methods of giving the dimensions for the use of the machinist. Without attempting to give an idea of how to control each case, which would be well nigh impossible, suffice it to say that the student should become impressed with the fact that he must *study the workman constantly* in order to be able to give him upon the drawing the necessary "complete instructions".

Order and Receiving Clerks. The order and receiving clerks are very easily satisfied as far as their part in the use of a working drawing is concerned. They simply need a designating mark, a pattern number for a casting, and a piece number for all other parts, together with the material and number wanted of each piece, in order that the proper orders may be written, and the material identified for recording its receipt in the shop or field. The number wanted is often given only on a separate "bill of material" which accompanies the drawing, but it is also quite general to note on the drawing in the title of each piece, the number wanted for one complete machine, whether billed elsewhere or not.

Specifications for Screw Threads. Exact drawings for the helix forming the thread of a screw are shown in Machine Drawing, Part II. These not only are difficult to draw, but they consume considerable time to produce accurately, therefore draftsmen have

adopted certain conventions to represent the thread on working drawings. Some of these conventions are shown in Fig. 17. Here *a* represents a single, right-hand, square thread; *b*, a single, right-hand, sharp V thread, and its modifications, the United States Standard or Seller's thread, and the Whitworth thread; *c* represents a left-hand, sharp thread; *d* is the most common convention for any thread of a V-shaped cross section; *e* for any thread on a very small bolt or set screw; *f* is a modification of *d*, there being no slope to the thread, which convention is preferred by some draftsmen; *g* represents a standard pipe thread, the taper on the sides of the pipe being neglected.

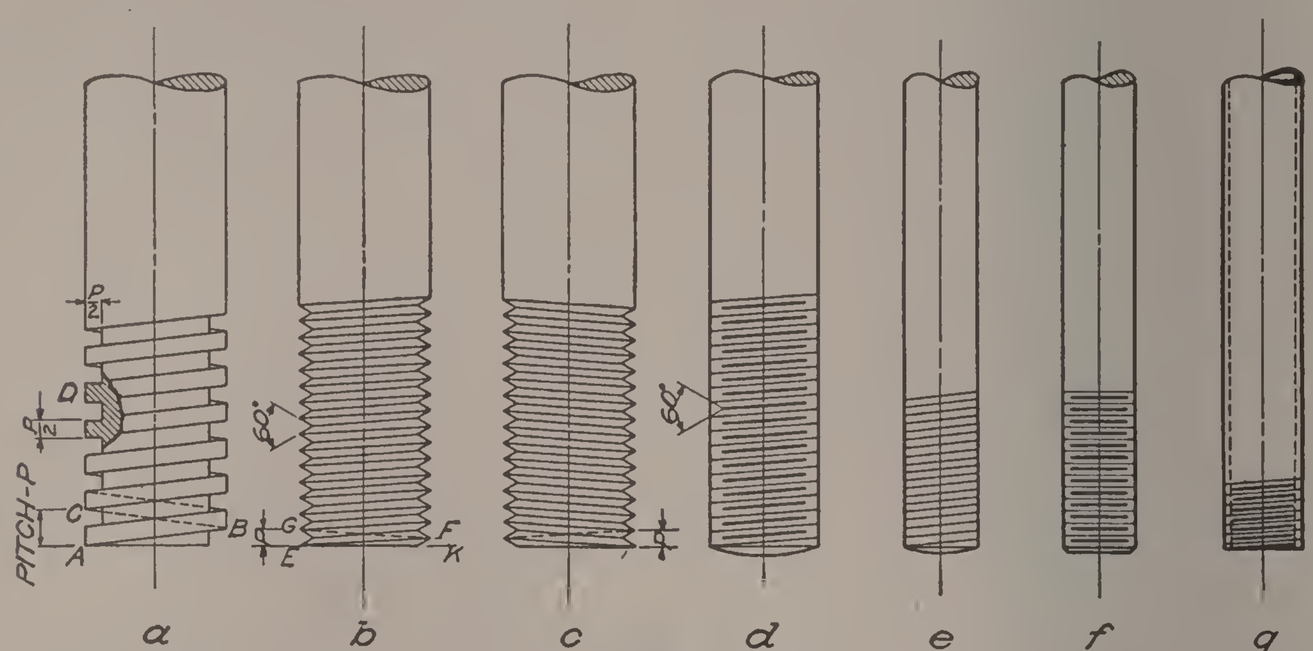


Fig. 17. Conventional Representations of Screw Threads

There are other conventions for threads in use, but the above are the most important ones. These certainly can not be mistaken for anything else, which is the real test for any conventional representation of an object.

Pitch. The pitch of a screw thread is the distance between corresponding points on two successive threads measured parallel to the axis. A small axial section is shown at *D* on the thread *a*. The square groove, which gives the thread its name, has a depth equal to about ½ the pitch. Starting at the bottom, and following the edge of a thread in making *one turn* around the bolt, or from *A* to *B* on the front and *B* to *C* on the rear, we find that the thread advances parallel to the axis a distance *AC*, or the pitch. As we

can see but one half of a turn it will be noted that a single right-hand thread advances a distance equal to $\frac{1}{2}$ the pitch along the right-hand side, and similarly for a single left-hand thread, the distance advanced would be $\frac{1}{2}$ the pitch on the left-hand side. The slope is, therefore, upward and to the right in the first case, and upward and to the left in the second case.

Drawing Thread. To draw the thread, space off the sides of the bolt with the dividers set to $\frac{1}{2}$ the pitch, determine the slope, whether for single, double, or triple thread, and fill in the tops of the threads. The depth of the thread, say $\frac{1}{2}$ the pitch, should then be laid off on each side and the lines drawn which show the visible portion of the bottom of the thread, thus completing the view for the ordinary convention. When the slope is considerable, as in this case, a small portion of the rear thread becomes visible, and may be shown.

For the thread at *b* it will be readily seen that an axial section would give V grooves, and as the standard angle for the grooves of the thread in this country is 60°, the projections are equilateral triangles. As before, if we follow a thread around the bolt, or from E to F on the front, and F to G on the back, we find for the single thread screw that the visible portion of the thread EF advances along the right-hand side a distance equal to $\frac{1}{2}$ the pitch. Hence starting at the bottom, laying off the distance KF equal to $\frac{1}{2}$ the pitch on the right-hand side, and connecting E to F, we have the slope of the thread determined. Spacing the pitch on the left-hand side for such distance as is required, we may then draw through these points lines parallel to EF, or the top lines of the thread. The V's may then be drawn with the aid of a T square and 30° triangle, after which the bottom of the threads may be connected. It will be noted that the top of the thread on one side is directly opposite the bottom of the thread on the other side. The left-hand V thread at *c* is drawn in a similar way to *b*, the thread advancing on the left-hand side instead of on the right.

Considerable care is required to get the V's uniform, and the more practical, usual, and in nearly all cases satisfactory method of showing the thread is given in the remaining figures.

The spacing for the conventions *d*, *e*, and *f* approximates the pitch of the thread, and time can be saved by the draftsman learning

to space with the eye rather than with the dividers. The light lines representing the top of the thread should be drawn first, the heavier lines for the bottom of the thread are then drawn midway between the light lines, stopping a short distance from the edges of the bolt. Often no difference in width is made between the lines representing the top and bottom of the threads, thus still further simplifying the conventional representation. It is well for the beginner to draw pencil lines limiting the bottom of the thread, so that the ends of the heavy lines will not be ragged or irregular. It rather improves the appearance of the thread to have the slant exaggerated in *d*, *e*, and *g*.

Threads in Sectional Pieces. Figs. 18, 19, and 20 illustrate the common method of representing threads when they occur in pieces which are drawn in cross section. The front half of the piece is supposed to be removed and we are looking at the back half. Now the thread on the back side of a screw slants the opposite way from the way it slants on the front side, and of course the same is true of the thread in a tapped hole. Consequently, since it is the back side of the hole which is seen, the slant of the lines which represent the thread is opposite to the direction they would have were we looking at the front side of the screw which goes into the hole. We have just learned that for a right-hand thread on a screw the lines slant upward from left to right, and therefore for a right-hand thread seen on the back side of a tapped hole, the lines will slant upward from right to left. In other words, for a right-hand thread in a hole which comes in a cross section, the lines slant the same as they would on the front of a left-hand thread on a bolt; and for a left-hand thread in a sectioned hole, the slant is the same as for a right-hand thread on a bolt.

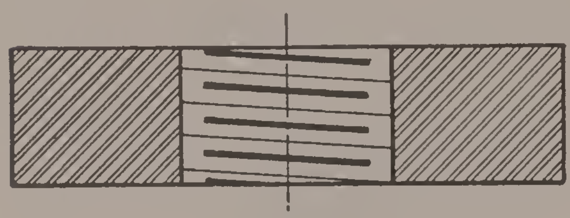


Fig. 18. Conventional Drawing for Threads in Sectional Pieces

Fig. 19 is a piece which has a smooth hole through it and a thread on the outside. Here the entire thread is invisible, except at the contour of the cylinder, and must be indicated by the notches. These are drawn by spacing off the distance which is used for the pitch and from the points thus found drawing lines with the triangle which make an angle of 60° with the axis of the cylinder. For a

TABLE I

United States Standard Screw Threads

Diameter of Bolt	Threads per Inch	Diameter of Bolt	Threads per Inch	Diameter of Bolt	Threads per Inch
$\frac{1}{4}$	20	$\frac{5}{8}$	11	$1\frac{3}{8}$	6
$\frac{5}{16}$	18	$\frac{3}{4}$	10	$1\frac{1}{2}$	6
$\frac{3}{8}$	16	$\frac{7}{8}$	9	$1\frac{5}{8}$	$5\frac{1}{2}$
$\frac{7}{16}$	14	1	8	$1\frac{3}{4}$	5
$\frac{1}{2}$	13	$1\frac{1}{8}$	7	$1\frac{7}{8}$	5
$\frac{9}{16}$	12	$1\frac{1}{4}$	7	2	$4\frac{1}{2}$

TABLE II

Whitworth Standard Screw Threads

Diameter of Bolt	Threads per Inch	Diameter of Bolt	Threads per Inch	Diameter of Bolt	Threads per Inch
$\frac{1}{4}$	20	$\frac{5}{8}$	11	$1\frac{3}{8}$	6
$\frac{5}{16}$	18	$\frac{3}{4}$	10	$1\frac{1}{2}$	6
$\frac{3}{8}$	16	$\frac{7}{8}$	9	$1\frac{5}{8}$	5
$\frac{7}{16}$	14	1	8	$1\frac{3}{4}$	5
$\frac{1}{2}$	12	$1\frac{1}{8}$	7	$1\frac{7}{8}$	$4\frac{1}{2}$
$\frac{9}{16}$	12	$1\frac{1}{4}$	7	2	$4\frac{1}{2}$

single thread the notches on one side have their outer points opposite the inner points of the notches on the other side. For a double thread the notches are directly opposite each other.

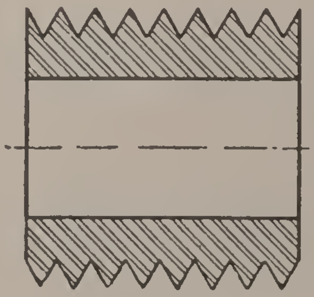


Fig. 19. Conventional Drawing for Threads in Sectional Pieces

Fig. 20 shows two ways of quarter-sectioning a threaded piece, the only difference being that on one the contour of the sectional part is drawn a straight line, while on the other the contour is notched. Either one may be used. The straight contour can, of course, be drawn much more quickly and in places where there is no danger of sacrificing clearness it should be used for that reason. If the drawing is somewhat complicated, so that without the notches it might not be quite clear that the piece was threaded, the notches should be used.

As has already been suggested, the student will doubtless find many other customs in the matter of drawing threads which are

quite as good as the above. These have been given as ones which are common, and easily drawn. As a matter of convenience Tables I and II are given, which show the number of threads per inch on some of the most common sizes of bolts, according to the standard adopted by the United States Government, and the Whitworth or English standard.

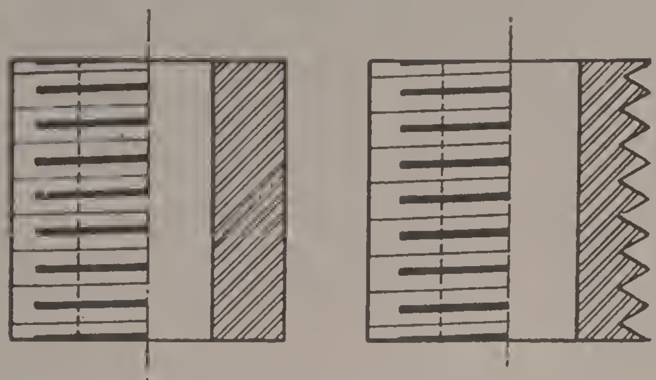


Fig. 20. Conventional Drawing for Threads in Sectional Pieces

Specifications for Bolts and Nuts. A bolt is a cylindrical bar upset at one end to form a head and having a screw thread cut at the other end.

A nut is a hollow piece of metal in which a screw thread has been cut.

A right-hand bolt has its thread so cut that its nut goes on, or advances along the axis of the bolt, when turned in the same direction as the hands of a watch. A left-hand bolt has its thread so cut

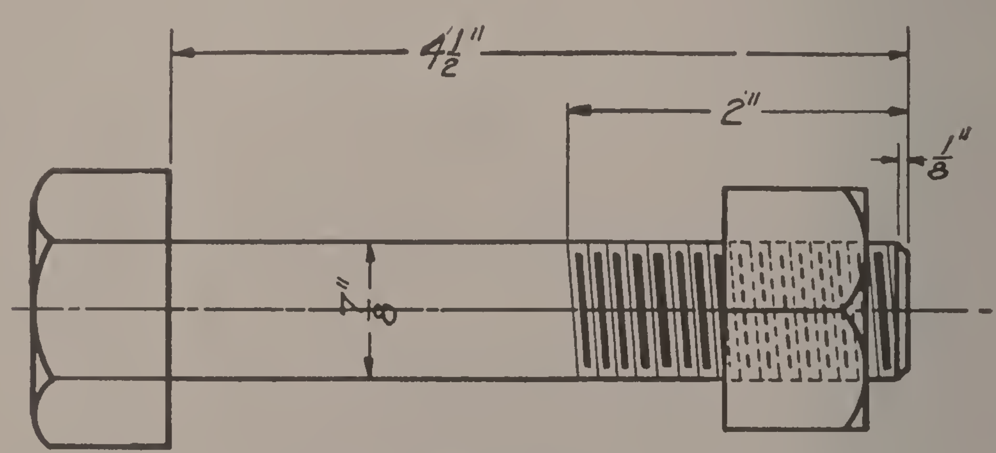


Fig. 21. Conventional Drawing for Machine Bolt and Nut

that its nut must be turned opposite to the hands of a watch in order to have it go on.

Hexagonal Bolt Head and Nut. Figs. 21 and 22 show conventional drawings of a $\frac{7}{8}$-inch machine bolt having a hexagonal head and nut. The head is simply a hexagonal prism which has been chamfered, *i.e.*, the corners rounded off so that the top view shows a circle inscribed in a hexagon, see Fig. 23. This top view has been omitted in Figs. 21 and 22, the conventional drawing being considered sufficient to show that the head is hexagonal, yet some

draftsmen prefer to specify whether the head and nut are hexagonal or square, thus, "SQ. HD.", "HEX. N." In this case the view across

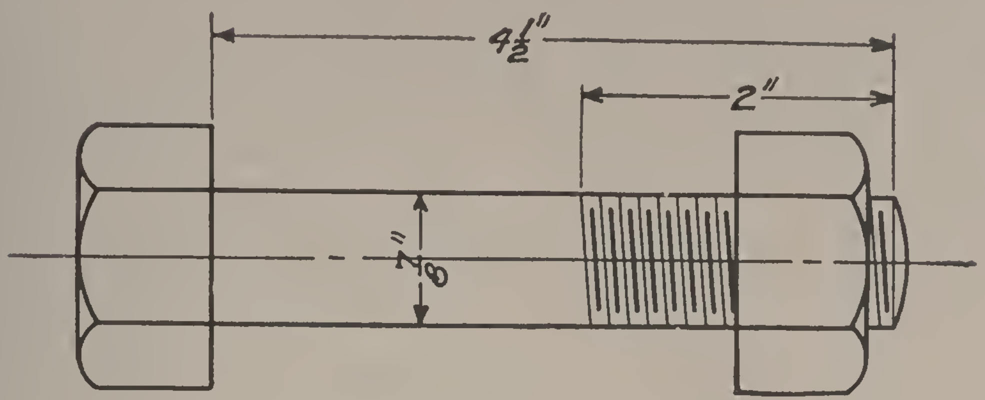


Fig. 22. Conventional Drawing for Machine Bolt and Nut

the long diameter is given in preference to the view across the flats, so that in close quarters the clearance of the corners may be readily seen. The shank of the bolt is represented as explained

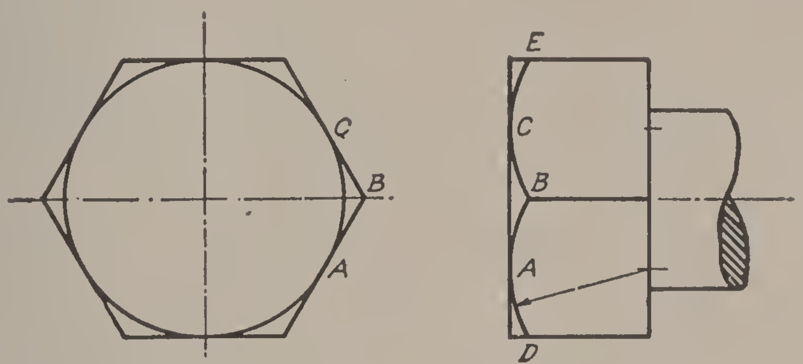


Fig. 23. Conventional Drawing for Machine Bolt Head

above for conventional threads. The point is chamfered a little in the figure so that it appears as the frustum of a cone.

Another style of point is shown in Fig. 24, where the end is

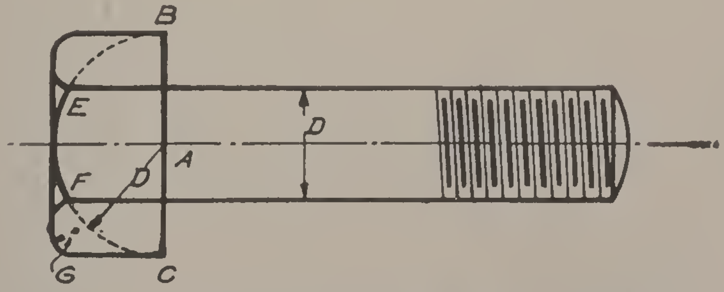


Fig. 24. Conventional Drawing for Machine Bolt

rounded off with a radius equal to about 1½ times the diameter. The lines which represent the thread should not cross the line drawn square across the bolt where the chamfer or rounding of the point

begins. Note that in Fig. 21 the threads have been shown dotted through the nut, while in Fig. 22 the simpler and more common method is followed of omitting the dotted threads and showing the long diameter of the nut.

The dimensions given are all that are necessary for the workman to make a standard bolt and nut. Some draftsmen prefer to show the length of bolt and thread from the base of the frustum or spherical end, as in Fig. 22, but this does not at once give the total length under the head, which is usually the important figure. In case dimensions for the head are needed the thickness and the

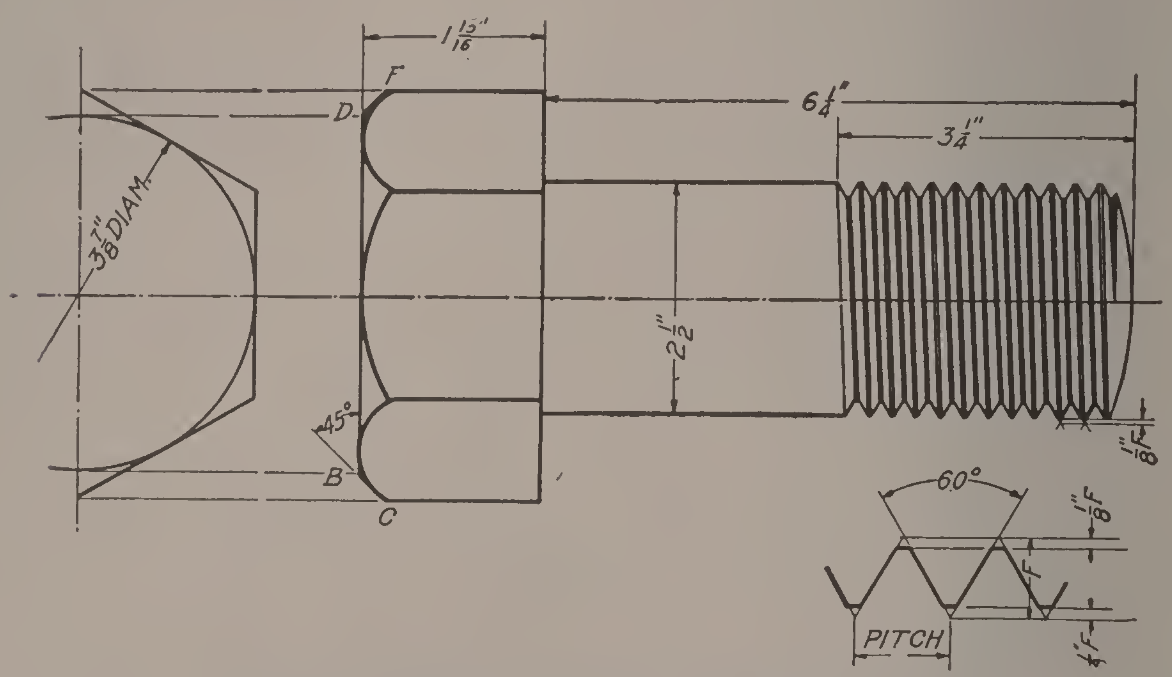


Fig. 25. Machine Bolt with U. S. Standard Thread

distance across flats should be given, as obtained from the table of proportions on page 25. If standard threads are not used, then the number of threads per inch must be given.

A method for making a conventional drawing of a hexagonal bolt head or nut is shown in Fig. 24. From A as a center describe an arc with a radius equal to the diameter of the bolt, making it intersect the perpendicular to the center line through A at points B and C. Continue the sides of the bolt until they intersect the arc at E and F, and draw lines through B and C parallel to sides of bolt. Draw a tangent to the arc parallel to BC for the top of the head. Find by trial the radius G and draw the arcs for the sides of the head. It will be noted that the long diameter of the hexagon by this method is twice the diameter of bolt, which is practically

true to the standard table for bolts under 1-inch diameter, and sufficiently exact for the larger sizes in common use.

Fig. 25 is a drawing to scale of a $2\frac{1}{2}$-inch rough bolt, having a hexagonal head and United States standard thread. Dimensions for the height and width of the head have been taken from table of bolt heads on page 25. The width of the head, $3\frac{7}{8}''$, is the diameter of the chamfer circle and is the first portion of the plan view to be drawn. Then the hexagon is circumscribed about the chamfer circle. Project the width of the faces and BD for the flat portion of the top. Assuming the chamfer to be conical and at 45° with the axis, draw lines BC and DF. The curves of intersection are approximated by arcs of circles springing from F and C and drawn tangent to BD.

The enlarged thread section below shows that the thread is flattened at top and bottom by cutting off $\frac{1}{8}$ of the depth F of the V thread. Note that the pitch of the thread is laid off on a line located outside of the true diameter of the bolt by an amount equal to the portion cut off the ordinary sharp V thread. The end is rounded with a radius equal to the diameter, or preferably $1\frac{1}{2}$ times the diameter of the bolt.

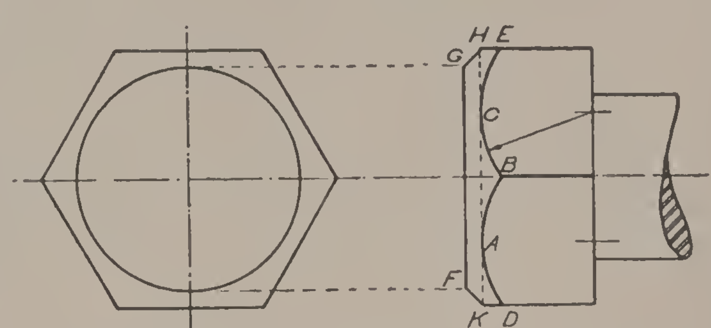


Fig. 26. Hexagonal Bolt Head with Chamfer

Two views, plan and elevation, of two faces of a hexagonal bolt head are given in Fig. 23. The chamfer circle is tangent to the sides of the hexagon, which means that the tool, in making the chamfer, cuts off the corners of the top as at ABC. The true curves DAB and BCE are lines of intersection of a cone or sphere with a hexagonal prism and may be easily obtained by the principles of projection. A simpler and much more convenient method is to approximate these curves with arcs of circles, using the height of the head as a radius, as shown.

In case it is desired to show more chamfer as in Fig. 26, the top of the head may be cut off at FK and GH at an angle of 30° or 45°, and the diameter of the chamfer circle is projected to the plan view as shown. The width of the hexagon is the same as before and is readily projected from the plan view. The curves of inter-

section DAB and BCE are drawn as arcs of circles, but instead of being tangent to the top they are tangent to the line KH, which indicates the place where the chamfer cuts the flat sides of the hexagon.

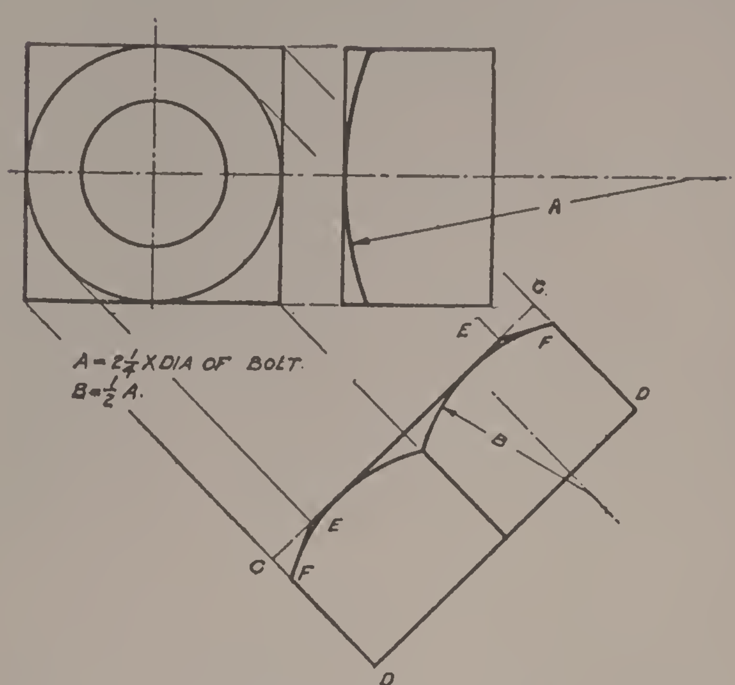


Fig. 27. Three Views of Square Head or Nut with Chamfer

Square Head and Nut. Fig. 27 shows three views of a square head or nut with chamfer corresponding to that on the hexagonal head in Fig. 23; and Fig. 28 shows the square head or nut chamfered to correspond to Fig. 26. Referring first to Fig. 27, the arc on the side view which shows the short diameter of the nut is drawn with a radius A, equal to two and one-quarter times the diameter of the bolt on which the head or nut belongs. The arcs on the other side view are drawn with a radius B, equal to one-half of A. The lines EF are drawn from

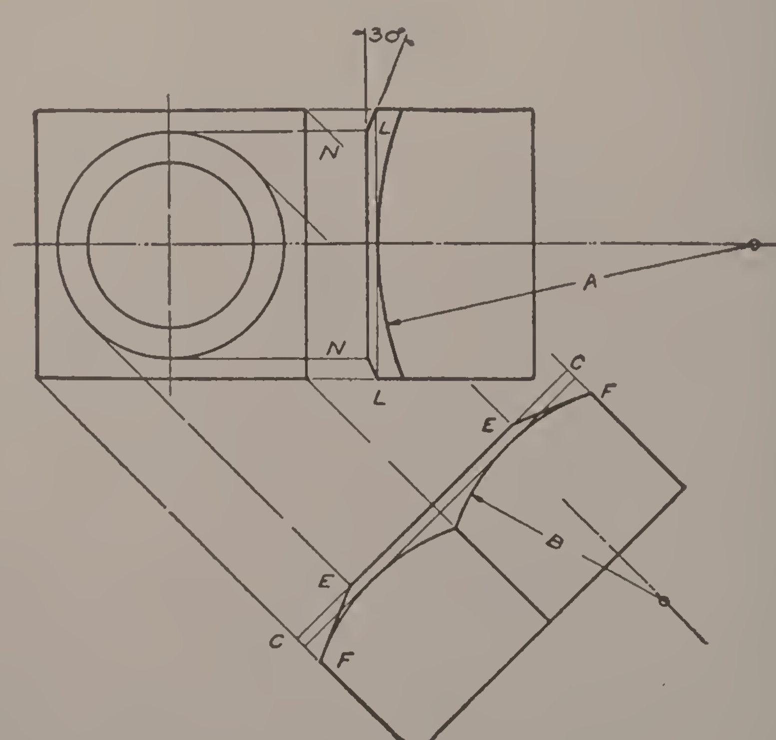


Fig. 28. Three Views of Square Head or Nut with Chamfer

points E tangent to the arcs, and it will be found that the points of tangency will come almost at the points where the arcs cut the

TABLE III

Rough Square and Hexagon Bolt Heads. U. S. Standard

(FRANKLIN INSTITUTE)

Diameter of Bolt	Width of Head	Thickness of Head	Diameter of Bolt	Width of Head	Thickness of Head
$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	1	$1\frac{5}{8}$	$\frac{13}{16}$
$\frac{5}{16}$	$\frac{19}{32}$	$\frac{19}{64}$	$1\frac{1}{8}$	$1\frac{13}{16}$	$\frac{29}{32}$
$\frac{3}{8}$	$\frac{11}{16}$	$\frac{11}{32}$	$1\frac{1}{4}$	2	1
$\frac{7}{16}$	$\frac{25}{32}$	$\frac{25}{64}$	$1\frac{3}{8}$	$2\frac{3}{16}$	$1\frac{3}{32}$
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{7}{16}$	$1\frac{1}{2}$	$2\frac{3}{8}$	$1\frac{3}{16}$
$\frac{9}{16}$	$\frac{31}{32}$	$\frac{31}{64}$	$1\frac{5}{8}$	$2\frac{9}{16}$	$1\frac{9}{32}$
$\frac{5}{8}$	$1\frac{1}{16}$	$\frac{17}{32}$	$1\frac{3}{4}$	$2\frac{3}{4}$	$1\frac{3}{8}$
$\frac{3}{4}$	$1\frac{1}{4}$	$\frac{5}{8}$	$1\frac{7}{8}$	$2\frac{15}{16}$	$1\frac{15}{32}$
$\frac{7}{8}$	$1\frac{7}{16}$	$\frac{23}{32}$	2	$3\frac{1}{8}$	$1\frac{9}{16}$
			$2\frac{1}{4}$	$3\frac{1}{2}$	$1\frac{3}{4}$
			$2\frac{1}{2}$	$3\frac{7}{8}$	$1\frac{15}{16}$

TABLE IV

Rough Square and Hexagon Nuts. U. S. Standard

(FRANKLIN INSTITUTE)

Diameter of Bolt	Width of Nut	Thickness of Nut	Diameter of Bolt	Width of Nut	Thickness of Nut
$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	1	$1\frac{5}{8}$	1
$\frac{5}{16}$	$\frac{19}{32}$	$\frac{5}{16}$	$1\frac{1}{8}$	$1\frac{13}{16}$	$1\frac{1}{8}$
$\frac{3}{8}$	$\frac{11}{16}$	$\frac{3}{8}$	$1\frac{1}{4}$	2	$1\frac{1}{4}$
$\frac{7}{16}$	$\frac{25}{32}$	$\frac{7}{16}$	$1\frac{3}{8}$	$2\frac{3}{16}$	$1\frac{3}{8}$
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{3}{8}$	$1\frac{1}{2}$
$\frac{9}{16}$	$\frac{31}{32}$	$\frac{9}{16}$	$1\frac{5}{8}$	$2\frac{9}{16}$	$1\frac{5}{8}$
$\frac{5}{8}$	$1\frac{1}{16}$	$\frac{5}{8}$	$1\frac{3}{4}$	$2\frac{3}{4}$	$1\frac{3}{4}$
$\frac{3}{4}$	$1\frac{1}{4}$	$\frac{3}{4}$	$1\frac{7}{8}$	$2\frac{15}{16}$	$1\frac{7}{8}$
$\frac{7}{8}$	$1\frac{7}{16}$	$\frac{7}{8}$	2	$3\frac{1}{8}$	2
			$2\frac{1}{4}$	$3\frac{1}{2}$	$2\frac{1}{4}$
			$2\frac{1}{2}$	$3\frac{7}{8}$	$2\frac{1}{2}$

lines CD. Points E are found by projecting from the plan view as indicated.

In Fig. 28, the construction is similar. The points N are first found by projecting from the top and bottom of the circle in the plan view; then the lines NL are drawn, making angles of 30° with the line NN. (The proportions for the radii which are given, hold good only when the angle of 30° is used.) Next draw the construction line LL and draw the arc tangent to it with a radius A equal to two and one-quarter times the diameter of the bolt, the same as in Fig. 27. To draw the chamfer in the other side view, draw the

construction line parallel to and at a distance from CC equal to the distance LL from NN and draw the arcs tangent to this line with radius B equal to one-half of A. The lines EF are then drawn as explained for Fig. 27.

Most of the bolts in common use are made standard sizes, that is, for a certain diameter of bolt there are a corresponding standard diameter and thickness for the head and the nut, and a standard number of threads per inch, so that if the bolt which the draftsman wishes to use has these standard dimensions they may be omitted from the drawing and a note made that the bolt is standard. Then the only dimensions necessary to be given are the diameter, the length under the head, and the length of the threaded part.

Tables III and IV give the United States standard sizes of square and hexagonal heads and nuts for bolts. The columns headed "Width of Nut" and "Width of Head" give the shortest dimension of the square or hexagon, that is, the diameter of the inscribed circle, or the distance across flats. The standard number of threads per inch can be found from the table already given.

Specifications for Pipes and Pipe Threads. *Kinds of Pipe.* The various kinds of pipe in common use are made to standard sizes, and as the draftsman very often comes in contact with piping we will consider it briefly. The kinds commonly used are wrought-iron or steel pipe, brass pipe made to the size of wrought-iron pipe, and cast-iron pipe. The cast-iron pipe is made of different weights and form, according to the purpose for which it is to be used. Standard wrought-iron pipe is rated by its nominal inside diameter, although the actual diameter does not in most cases quite agree with the nominal diameter. For example, a $\frac{1}{4}$-inch pipe is a pipe, the hole in which is supposed to be $\frac{1}{4}$ inch in diameter, but if measured it will be found to be nearly $\frac{1}{8}$ of an inch larger.

Standard Threads and Fittings. The threads on pipes and pipe fittings are also made to standard, and stock taps and dies made for the various sizes of pipe. These taps and dies are spoken of, or described, by stating the size of the pipe for which they are intended. For example, a $\frac{1}{4}$-inch pipe tap is a tap of the proper size, shape, and number of threads per inch to cut the thread in a hole to receive a $\frac{1}{4}$-inch pipe. Threaded holes are made tapering for pipes, the standard taper being $\frac{3}{4}$ inch per foot, that is, the diameter of the

TABLE V

Standard Sizes of Wrought-Iron Pipe

Nominal Size	⅛	¼	⅜	½	¾	1	1¼	1½	2
Actual Inside Diameter	.27	.364	.494	.623	.824	1.048	1.38	1.611	2.067
Outside Diameter	.405	.54	.675	.84	1.05	1.315	1.66	1.90	2.375
Nominal Size	2½	3	3½	4	4½	5	6	7	8
Actual Inside Diameter	2.468	3.067	3.548	4.026	4.508	5.045	6.065	7.023	7.982
Outside Diameter	2.875	3.50	4.00	4.50	5.00	5.563	6.625	7.625	8.625

TABLE VI

Standard Threads for Wrought-Iron Pipe

Nominal Size of Pipe	⅛	¼	⅜	½	¾	1	1¼	1½	2
Threads per Inch	27	18	18	14	14	11½	11½	11½	11½
Nominal Size of Pipe	2½	3	3½	4	4½	5	5½	7	8
Threads per Inch	8	8	8	8	8	8	8	8	8

holes decreases at the rate of $\frac{3}{4}$ inch per foot. In representing a hole which is threaded with a pipe tap, the hole is drawn of a diameter at its larger end about equal to the outside diameter of the pipe which is to be screwed into it, and is drawn tapering. It is well to make the taper considerably greater than the actual taper, so that the person looking at the drawing may see at a glance that the hole is for a pipe.

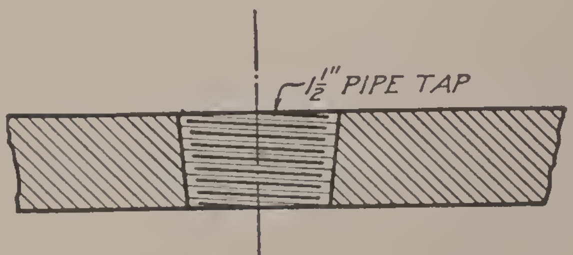


Fig. 29. Conventional Drawing of Thread in a Pipe Fitting

The thread is indicated in one of the conventional ways previously explained, but the number of threads per inch and the diameter of the hole need not be given; instead, a note is made that the hole is tapped for a certain size pipe. Fig. 29 illustrates this.

Tables V and VI which show the standards for wrought-iron pipe may be found convenient.

Scale Drawings. When the object which is to be drawn is not so large but that it can be easily shown actual size (or full size as it

is called) on a sheet of paper of convenient dimensions, it is good practice to draw the piece full size. In many cases, however, the machine, or the building, or whatever is to be drawn, is so large that it would be impossible to draw it full size. Then the drawing is made to some reduced scale, that is, all the dimensions are drawn smaller than the actual dimensions of the object itself; all dimensions being reduced in the same proportion. For example, if a piece is to be drawn $\frac{1}{2}$ size, the distance from one point to another on the drawing would be $\frac{1}{2}$ what it is on the piece itself; if the drawing is $\frac{1}{4}$ size, the distance on the drawing would be $\frac{1}{4}$ what it is on the piece itself, and so on. In dimensioning such a drawing, the dimension which is written on the drawing is the *actual dimension* of the piece, and not the distance which is measured on the drawing. This fact must be very clearly understood by the student.

Methods of Reducing Dimensions. The common method of reducing all the dimensions in the same proportion is to choose a certain distance and let that distance represent one foot, this distance is then divided into twelve parts and each one of these parts represents an inch; then if half and quarter inches are required these twelfths are subdivided into halves, quarters, etc., until the subdivisions become so small that they cannot be used. We now have a scale which represents the common foot rule with its subdivisions into inches and fractions; but our new foot is smaller than the ordinary distance which we call a foot, and of course its subdivisions are proportionately smaller. When we make a measurement on the drawing we make it with our reduced foot rule and when we make a measurement on the machine itself we make it with the common foot rule.

Draftmen's Scales and Their Use. Draftsmen's scales can be bought which have different distances thus divided, so that if the draftsman wishes to draw a piece $\frac{1}{4}$ size he looks over his scale until he finds a distance of 3 inches (which is of course $\frac{1}{4}$ of a foot) divided as explained above, and he uses this to measure with on his drawing. His drawing would then be made to a scale of 3 inches to the foot. In the same way, if he wishes to make his drawing $\frac{1}{12}$ size he finds on his scale 1 inch divided into twelfths and fractions of twelfths and uses this as his standard of measurement; if he wishes to make his drawing $\frac{1}{48}$ size he uses a quarter inch with its subdivisions.

Sometimes if the piece to be drawn is too small to be satisfactorily shown full size, the drawing is made to an enlarged scale, such as twice size, three times size, etc.

The mistake of choosing the wrong distance to use on a scale is often made. For example, if one wishes to draw a piece $\frac{1}{4}$ size, he may look over his scale for a place marked $\frac{1}{4}$, and use this for his

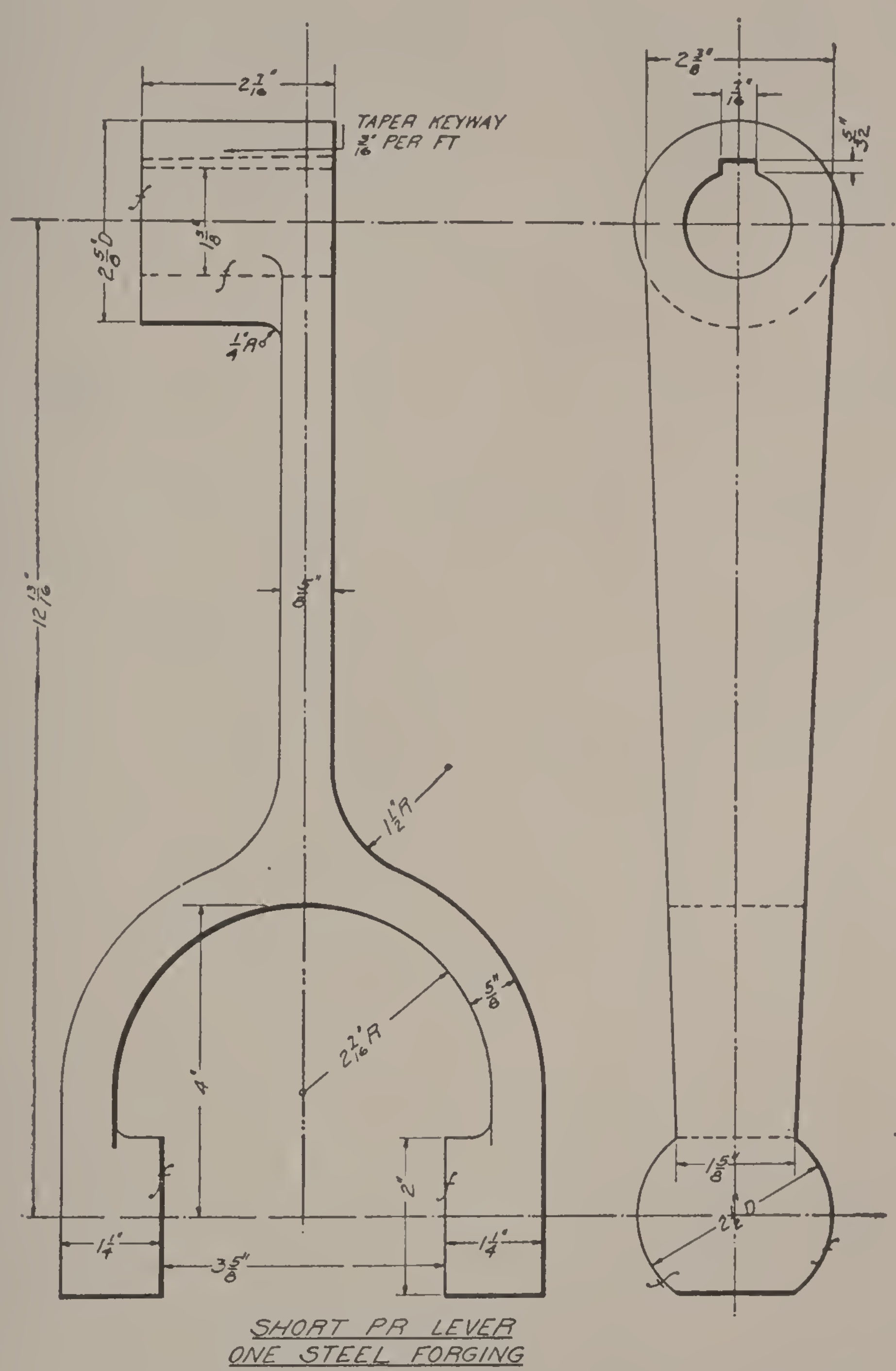
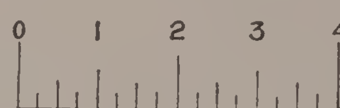


Fig. 30. Reduced Scale Drawing. Actual Scale, 3″=1′

standard for $\frac{1}{4}$ size, which is wrong. The figure on the scale indicates the distance which is divided up to represent 1 foot, so that the part of the scale which has $\frac{1}{4}$ marked on it means that $\frac{1}{4}$ of an inch is divided up into twelfths, or in other words, if a drawing is made according to that scale it will be $\frac{1}{48}$ size.

Usual Scales for Drawings. The best scales for shop drawings in the United States are those readily derived from the common foot rule, such as full size, 6 inches = 1 foot, 3 inches = 1 foot, $1\frac{1}{2}$ inches = 1 foot. These are the most common, most easily read from an ordinary scale, and one of these can usually be adopted. The student should learn to read these from an ordinary scale without being confined to a special graduation. To do this it is not necessary to divide each dimension by 2, 4, and 8 to get $\frac{1}{2}$ size, $\frac{1}{4}$ size, or $\frac{1}{8}$ size, and then lay down the result. For $\frac{1}{2}$ size, or 6 inches = 1 foot, $\frac{1}{2}$ inch on an ordinary rule represents 1 inch. Hence, each $\frac{1}{2}$ inch may be read as 1 inch, and its subdivisions accordingly, thus:

For 3 inches = 1 foot, or $\frac{1}{4}$ size, $\frac{1}{4}$ inch represents 1 inch, and looks thus:



For $1\frac{1}{2}$ inches = 1 foot, or $\frac{1}{8}$ size, $\frac{1}{8}$ inch represents 1 inch, and looks thus:

It is very easy to get accustomed to this, and it saves much time and trouble hunting up a special scale every time.

The other allowable scales, less common, but sometimes necessary on large work, are 1 inch = 1 foot, $\frac{3}{4}$ inch = 1 foot, $\frac{1}{2}$ inch = 1 foot, $\frac{3}{8}$ inch = 1 foot, $\frac{1}{4}$ inch = 1 foot, and $\frac{1}{8}$ inch = 1 foot. To use these scales conveniently, special graduation is desirable.

Every drawing should have the scale to which it is made plainly marked upon it, as a part of, or adjacent to, the title.

Fig. 30 shows a detail which has been reduced in making the cut so that its dimensions are on a scale of 3 inches per foot, or $\frac{1}{4}$ size. By applying his scale to this cut and comparing the readings of his scale with the dimensions as given, the student will gain a clear understanding of a reduced scale drawing. None of the other cuts in this book are reduced for the purpose of scaling, hence have no even relation to their dimensions as given.

GENERAL SYSTEM FOR SHOP DRAWINGS

The principles of detail drawings having been thoroughly discussed in the preceding pages, the general system to be followed in preparing shop drawings for the workman's use will now be outlined and illustrated.

DETAILS OF PREPARATION

First Step—Sketches. As previously stated, for a new machine, the original sketches will be supplied by the designer, and it is the duty of the detail draftsman to read and interpret them; or the designer may furnish a rough general layout to scale, from which the detail draftsman must pick out the details, scaling off the dimensions.

Oftentimes certain details of an existing machine have to be copied, in which case the sketches will have to be made by the detail draftsman himself, from the machine. Proficiency in the art of making sketches is a very valuable and necessary acquisition for any draftsman. Accuracy, completeness, clearness, and rapidity in making are the principal requirements for a good sketch.

The sketches should be made so clear, that even if they are laid aside for a long time they can be readily understood without depending at all upon memory. There is a strong tendency for the beginner to make his sketches hurriedly, thinking that when he comes to finish his drawing he can supply the details from memory. This is a bad plan and will lead to many mistakes. The sketches must be so clear and complete that anyone can read them who has never seen the machine. No attempt need be made to draw them to scale, but all dimensions, carefully measured from the machine, should be placed on the sketch.

Second Step—Pencil Drawing. After the sketches are made, the next step is the making of the pencil drawing from the sketches, accurately to scale. The size of the plate on which the drawing is to be made is usually fixed by some standard. Where many drawings are made and kept in an office, it is desirable to keep the plates of uniform size, as far as possible. It is good practice to have two or three standard sizes of plates, one for small, one for medium, and one for large drawings.

Assuming, then, that we have our paper tacked on the drawing board and the plate laid out, the next step will be to arrange the drawings of the various pieces on the plate so that there will be room for all and so that they may be properly placed with relation to each other. It may happen that there will not be room on one plate for all the pieces, but that two or more plates will be required. When the parts must be thus arranged on different plates, an effort

should be made to keep on the same plate those parts which belong together. For example, if we were drawing a lathe, the details of the parts of the head stock might form one plate, the apron another, and so on.

In locating the various pieces on a plate, they should be placed as nearly as possible in the same relative position to each other that they bear in the machine, except that they are separated. For example, if a nut belongs on the end of a screw, it is desirable to draw it on the same center line with the screw and at the end where it belongs. If a piece is vertical in the machine it should be vertical on the plate, and if horizontal in the machine, it should be horizontal on the plate.

The approximate location of the pieces on the plate may be easily decided by taking a small sheet of paper of about the same proportion as the plate, but perhaps $\frac{1}{4}$ or $\frac{1}{2}$ size, and sketching on it roughly the outline of the various pieces. The arranging of the plate should not be allowed to take much time, but should be done as rapidly as possible. After the location of each view of each piece is determined, the pencil drawing should begin (to scale) with one of the principal pieces. In almost all cases a center line is first drawn. It is better to carry along all the views of a piece at once, instead of completing one view at a time. The piece started should have all its views finished and completely dimensioned before another piece is begun; exceptions to this are sometimes necessary for special reasons. The lines should be drawn accurately, but no attempt need be made to obtain finish; thus, in order to save time, the lines may be run past the point where they should properly stop, etc. Nothing should be omitted, however.

Third Step—Tracing. Having finished the pencil drawing, the next step is the inking. In some offices the pencil drawing is made on a thin, tough paper, called bond paper, and the inking is done over the pencil drawing, in the manner with which the student is already familiar. It is more common to do the inking on thin, transparent cloth, called tracing cloth, which is prepared for the purpose. This tracing cloth is made of various kinds, the kind in ordinary use being what is known as "dull backs", that is, one side is finished and the other side is left dull. Either side may be used to draw upon, but most draftsmen prefer the dull side.

The tracing cloth is stretched smoothly over the pencil drawing and a little powdered chalk rubbed over it with a dry cloth, to remove the slight amount of grease or oil from the surface and make it take the ink better. The dust must be carefully brushed or wiped off with a soft cloth, after the rubbing, or it will interfere with the inking.

The drawing is then made in ink on the tracing cloth, after the same general rules as for inking on paper, but care must be taken to draw the ink lines exactly over the pencil lines on the paper underneath, which should be heavy enough to be easily seen through the tracing cloth. The ink lines should be firm and heavy to assure good blue prints. In tracing, it is better to complete one view at a time, because if parts of several views are traced and the drawing left for a day or two, the cloth is liable to stretch and warp so that it will be difficult to complete the views and make the new lines fit those already drawn and at the same time conform to the pencil lines underneath. For this reason it is well, when possible, to complete a view before leaving the drawing for any length of time, although of course on views in which there is a good deal of work this cannot always be done. In this case the draftsman must manipulate his tracing cloth and instruments to make the lines fit as best he can. A skillful draftsman will have no trouble from this source, but the beginner may at first find difficulty.

Inking on tracing cloth will be found by the beginner to be quite different from inking on the paper to which he has been accustomed, and he will doubtless make many blots and become discouraged with his first attempt to make a tracing. After a little practice, however, he will find that the tracing cloth is very satisfactory and that a good drawing can be made on it quite as easily as on paper.

The necessity for making erasures should be avoided, as far as possible, but when an erasure must be made a good ink rubber or typewriter eraser may be used. If the erased line is to have ink placed on it, such as a line crossing, it is better to use a soft rubber eraser. All moisture should be kept from the cloth.

Fourth Step—Blue Printing. The tracing, of course, cannot be sent into the shop for the workmen to use, as it would soon become soiled and in time destroyed, so that it is necessary to have some cheap and rapid means of making copies from it. These copies are

made by the process of blue printing, in which the tracing is used in a manner similar to the use made of a negative in photography.

Almost all drafting rooms have a frame for the purpose of making blue prints. These frames are made in many styles, some simple, some elaborate. A simple and efficient form is a flat surface usually of wood, covered with padding of soft material, such as felting. To this is hinged the cover, which consists of a frame similar to a picture frame, in which is set a piece of clear glass. The whole is either mounted on a track or on some sort of a swinging arm, so that it may readily be run in and out of a window.

The print is made on paper prepared for the purpose by having one of its surfaces coated with chemicals which are sensitive to sunlight. This coated paper, or blue-print paper, as it is called, is laid on the padded surface of the frame with its coated side uppermost; the tracing is laid over it right side up, and the glass pressed down firmly and fastened in place. Springs are frequently used to keep the paper, tracing, etc., against the glass. With some frames it is more convenient to turn them over and remove the backs. In such cases the tracing is laid against the glass, face down; the coated paper is then placed on it with the coated side against the tracing cloth.

The sun is allowed to shine upon the drawing for a few minutes, then the blue-print paper is taken out and thoroughly washed in clean water for several minutes and hung up to dry. If the paper has been recently prepared and the exposure properly timed, the coated surface of the paper will now be of a clear, deep blue color, except where it was covered by the ink lines, where it will be perfectly white.

The action has been this: Before the paper was exposed to the light the coating was of a pale yellow color, and if it had then been put in water the coating would have all washed off, leaving the paper white. In other words, before being exposed to the sunlight the coating was soluble. The light penetrated the transparent tracing cloth and acted upon the chemicals of the coating, changing their nature so that they became insoluble; that is, when put in water, the coating, instead of being washed off, merely turned blue. The light could not penetrate the ink with which the lines, figures, etc., were drawn, consequently the coating under these was not acted upon and it washed off when put in water, leaving a white

copy of the ink drawing on a blue background. If running water cannot be used, the paper must be washed in a sufficient number of changes until the water is clear. It is a good plan to arrange a tank having an overflow, so that the water may remain at a depth of about 3 or 4 inches.

The length of time to which a print should be exposed to the light depends upon the quality and freshness of the paper, the chemicals used, and the brightness of the light. Some paper is prepared so that an exposure of one minute, or even less, in bright sunlight, will give a good print, and the time ranges from this to twenty minutes or more, according to the proportions of the various chemcals in the coating. If the full strength of the sunlight does not strike the paper, as, for instance, if clouds partly cover the sun, the time of exposure must be lengthened.

Blue-print paper should not be exposed to bright actinic light except during the process of printing. It is not, however, so sensitive as the ordinary dry plate and may be handled in a subdued light if the exposure is very brief. When not in use the paper must be kept in a dry, dark place and should be hermetically sealed.

A more modern type of blue-print machine is the electric machine, usually arranged in the form of a vertical cylinder of glass, around which is placed the sensitized paper and the tracing, and along the longitudinal axis of which travels an electric arc lamp at a uniform speed. This speed is so adjusted that the right exposure is given to the sensitized paper. There are several other types of electric blue-printing machines, all based upon the same idea of uniform exposure of the sensitized paper to the rays of one or more arc lamps. These machines are a positive necessity to modern drawing offices, because of the uncertainty of sunlight, and, therefore, limited capacity for turning out prints. With the electric machines there is no limit, and they may be run to their full capacity 24 hours a day if desired.

FORMULA FOR BLUE-PRINT SOLUTION

Dissolve thoroughly and filter.

A.	Red prussiate of potash.	$2\frac{1}{2}$ ounces
	Water.	1 pint
B.	Ammonium-citrate of iron.	4 ounces
	Water.	1 pint

Use equal parts of A and B.

FORMULA FOR BLACK PRINTS

Negatives. White lines on blue ground; prepare the paper with:

Ammonium-citrate of iron	40 grains
Water	1 ounce

After printing wash in water.

Positives. Black lines on white ground; prepare the paper with:

Iron perchloride	616 grains
Oxalic acid	308 grains
Water	14 ounces

Develop in	Gallic acid	1 ounce
	Citric acid	1 ounce
	Alum	8 ounces

Use $1\frac{1}{4}$ ounces of developer to 1 gallon of water. Paper is fully exposed when it has changed from yellow to white.

Assembly Drawings. We have followed through the process of making a detail drawing, from the sketches to the blue print ready for the workmen. Such a detail drawing or set of drawings shows the form and size of each piece, but does not show how the pieces go together and gives no idea of the machine as a whole. Consequently, a general drawing or assembly drawing must be made, which will show these things. Usually two or more views are necessary, the number depending upon the complexity of the machine. Very often a cross section through some part of the machine, chosen so as to give the best general idea with the least amount of work, will make the drawing clearer.

The number of dimensions required on an assembly drawing depends largely upon the kind of machine. It is usually best to give the important over-all dimensions and the distance between the principal center lines. Care must be taken that the over-all dimensions agree with the sum of the dimensions of the various details. For example, suppose three pieces are bolted together, the thickness of the pieces, according to the detail drawing, being 1″, 2″ and $5\frac{1}{2}$″ respectively; the sum of these three dimensions is $8\frac{1}{2}$″ and the dimensions from outside to outside on the assembly drawing, if given at all, must agree with this. These over-all dimensions serve as a check and relieve the mechanic of the necessity of adding fractions.

ILLUSTRATIVE DRAWINGS

The following illustrative drawings show the common practice in making working drawings, which it would be tedious and difficult to formulate as rules to guide the student. By a careful study of the illustrations, all of which are practical working drawings of a variety of pieces, and a close following of the description, more can be learned as to making a drawing than by adhering to a multitude of rules. After a study of the preceding pages, expounding the principles involved, the student will find most of his further questions answered by reference to Figs. 31 to 50 inclusive. While he may find that the methods of lines and dimensions shown in these figures are in some ways different from those he may see or hear of from other quarters, he should remember that the language of drawing differs widely in usage. The result desired, however, is always the same, namely, *complete instructions to the workman.* This is the sole test of a good drawing, however made, and the student's aim should always be to satisfy this requirement.

Crank—*Rough Sketch.* In making working drawings of a machine the detail draftsman must secure the several dimensions of the parts, either by measuring the general layout which has been made by the designing draftsman, or he may be given a rough sketch of the part, which he is to develop into an exact working shop drawing. Sometimes he may himself be called upon to go into the shop and measure up the parts of an existing machine, making his own sketches, and then detail drawings from them. Such sketches, while of the roughest kind, must be accurately and completely dimensioned at the time the sketch is made, as it is not always convenient or possible to make subsequent trips to the machine to fill in lacking dimensions on the sketch. The making of satisfactory sketches is not as easy as would at first appear, but is quite an art in itself, acquired by systematic action and experience.

An illustration of a sketch of this kind is shown in Fig. 31, the subject being a crank, keyed and clamped to a shaft. The first thing to do is to sketch the piece roughly but with sufficient care to enable the dimensions to be put on. (A soft or medium pencil is the best for such purpose and any scrap of paper or a sketching pad will suffice.) Each portion of the piece should then be *separately con-*

sidered and carefully gone over to see that it is not only properly located but that it has the three dimensions, *length*, *breadth*, and *thickness* properly noted.

Thus in Fig. 31, the large hub should first be located by giving its distance $10\frac{1}{8}''$ from the center of the smaller hub, then its diameter $5\frac{3}{4}''$ should be given, the distance between its faces $3\frac{1}{2}''$, and $6''$ radius between them; next, the diameter of the hole to receive the shaft $2\frac{15}{16}''$, after which it is noted that it has a keyway, the dimensions of which are necessary. Then the boss for the clamping bolt should

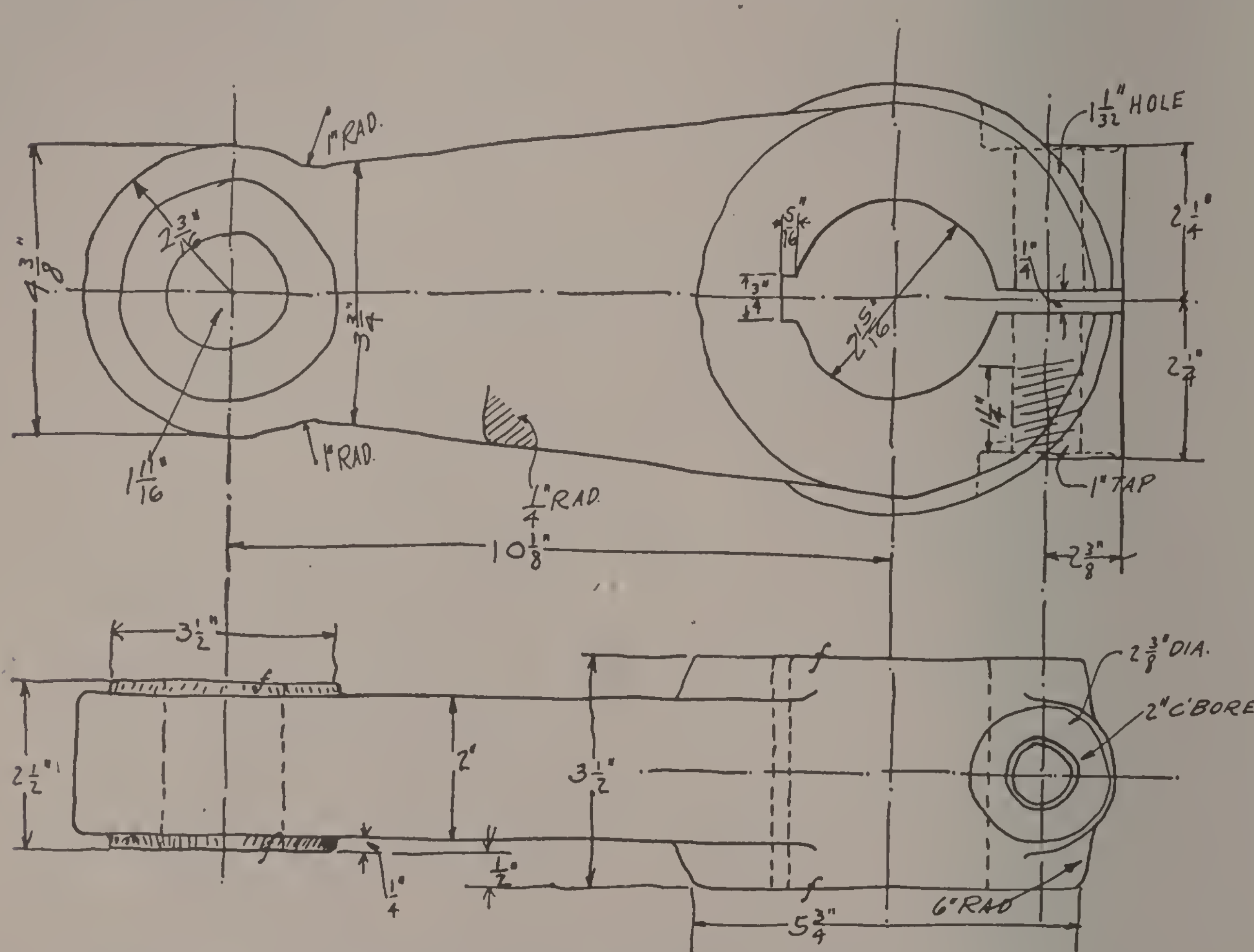


Fig. 31. Preliminary Sketch of Crank

be located by the figure $2\frac{3}{8}''$ to its center, its location in the other direction being on the center line of the arm. This boss has a diameter of $2\frac{3}{8}''$ and a length of $2\frac{1}{4}''$ each side of the center to the finished surface, the depth of the counterbore being $\frac{1}{16}''$, and the width of the slot to the bore $\frac{1}{4}''$, all of which dimensions should be carefully put on. The boss has a hole in it tapped at one end for a $1''$ bolt and drilled at the other end $1\frac{1}{32}''$. This completes the figuring of the large hub and we can proceed to dimension the other end of the arm. This has a diameter of $4\frac{3}{8}''$, the thickness of the arm being $2''$, and there are facing pads on either side $\frac{1}{4}''$ high, bringing

the total distance from face to face $2\frac{1}{2}''$; in order to show positively that these portions are central with the faces of the large hub, the figure $\frac{1}{2}''$ is put at one side; the diameter of these facing pads is $3\frac{1}{2}''$, and the hole through the head of the crank is $1\frac{11}{16}''$ diameter. Having put on the above figures we now have to provide a connection between the head of the crank and the hub, and it therefore becomes necessary to give figures, for the size of the arm; the thickness of the arm has been already given as $2''$, and the width being the same as the diameter of the hub, the side lines are simply drawn tangent to the same; at the smaller end the width may be conveniently given along a line tangent to the facing pad as $3\frac{3}{4}''$. The arm is filleted into the hub by $1''$ radius. The only thing now uncertain is whether the corners of the arm are sharp or rounded, and this is shown by the little section of the corner giving $\frac{1}{4}''$ radius.

The above description is tedious and the dimensions can probably be put on more quickly than the discussion of them can be read, but it should be especially noted that the systematic method has been followed of taking each part of the piece separately and dimensioning it before taking up any other part. While this is not always entirely possible to do in complicated pieces, yet it is absolutely necessary that in general this principle be always followed; otherwise it is impossible to be sure that all dimensions are on.

The description above also applies to the dimensioning of the piece after it is drawn in detail, this being represented in Fig. 32.

Referring to this figure, the bold character of the drawing should be noted, the solid lines being strong and of absolutely different character from the center or dimension lines. There is no uncertainty about the direction or termination of the lines; the figures are bold, plainly made, and absolutely clear; there can be no possible excuse for the workman to read any of the lines or dimensions wrongly. In other words, the drawing satisfies the definition of a working drawing, as previously given, in that *it conveys absolutely definite instructions to the workman, expressed in the simplest and most straightforward way.*

Finished Drawing. On most machine parts a portion only of the surfaces are finished; and these are usually indicated, as previously noted, by the small letter *f* placed across the line representing

the surface; this indicates to the pattern maker that he is to allow extra stock on the pattern, so that when the rough casting is made there will be sufficient metal to enable the finishing cut to be taken to the proper dimension. These finished surfaces are the most important surfaces of the piece, to which all the other parts have to be related. In order that the several parts of the machine may properly go together, it is necessary for the draftsman, in putting on the figures, to start from some one finished surface, and so arrange

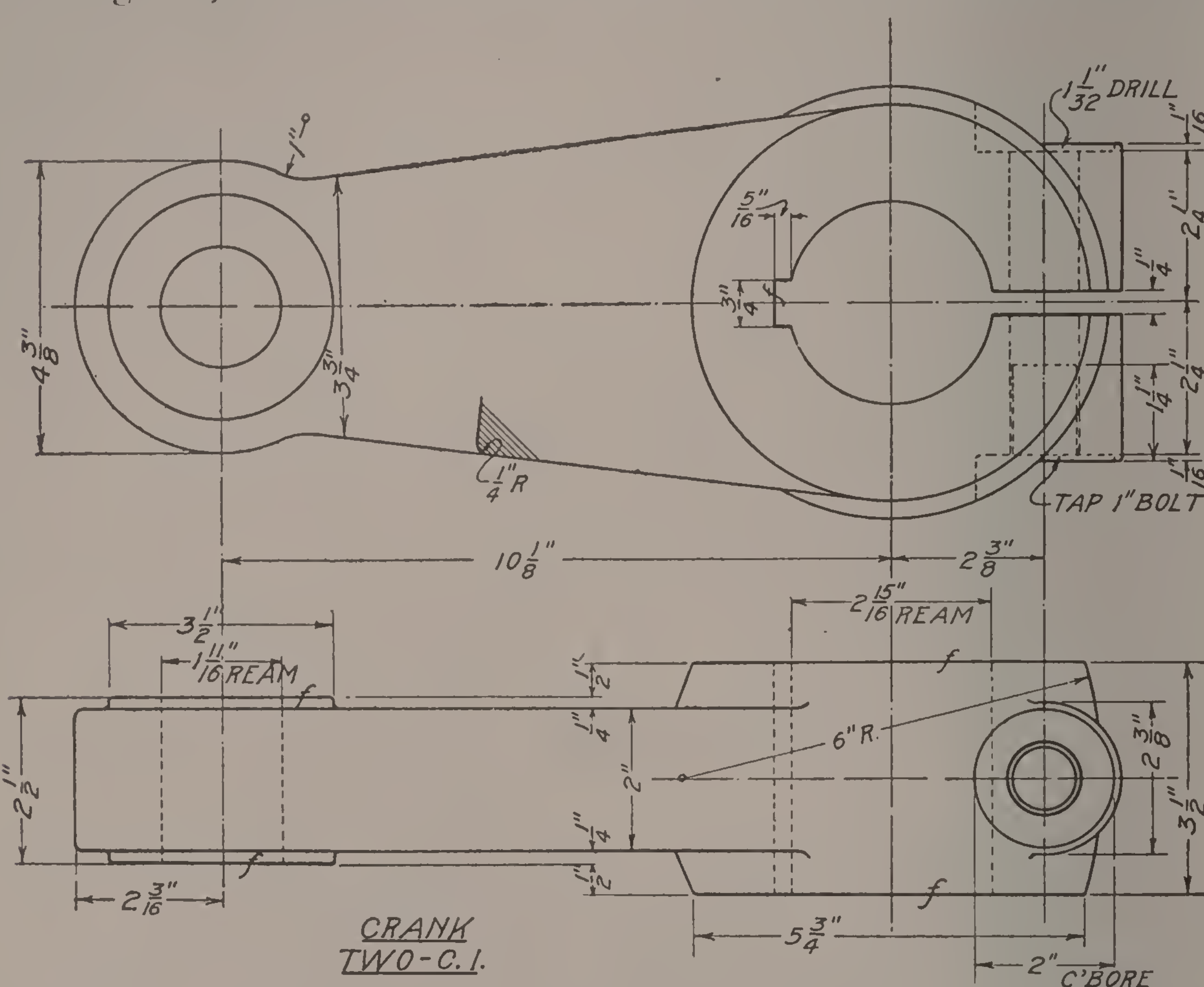


Fig. 32. Detail Drawing of Crank

the figures that the machinist can readily work from one finished surface to another. In Fig. 32 the dimensions of the rough parts as given may not be exactly maintained in the casting, but the distances between the finished surfaces must be exactly secured. The method of figuring a keyway is illustrated in this figure, and it should be carefully noted that the depth of the keyway ($\frac{5}{16}''$) is given from the corner where the side of the keyway intersects the bore; this is because the depth of the keyway is readily measured by scale from this point.

The thread for the 1″ bolt is indicated in this case by a double line, the inside line representing the bottom, the outside representing

the top of the thread, while the lines of the helix are entirely omitted. This is not as common a method of representing a thread as the conventional method previously described.

Bell Crank. Fig. 33 shows a bell crank fastened to its shaft by means of a set screw, the same general features being noted in this as in the preceding figure. A further point is the method of expressing the distance between the faces of the principal hub and the smaller hub, "10″ less $\frac{1}{64}$″". This method of stating a dimension is quite common among certain manufacturers, as it saves giving odd dimensions and conveys more quickly to the workman's mind what

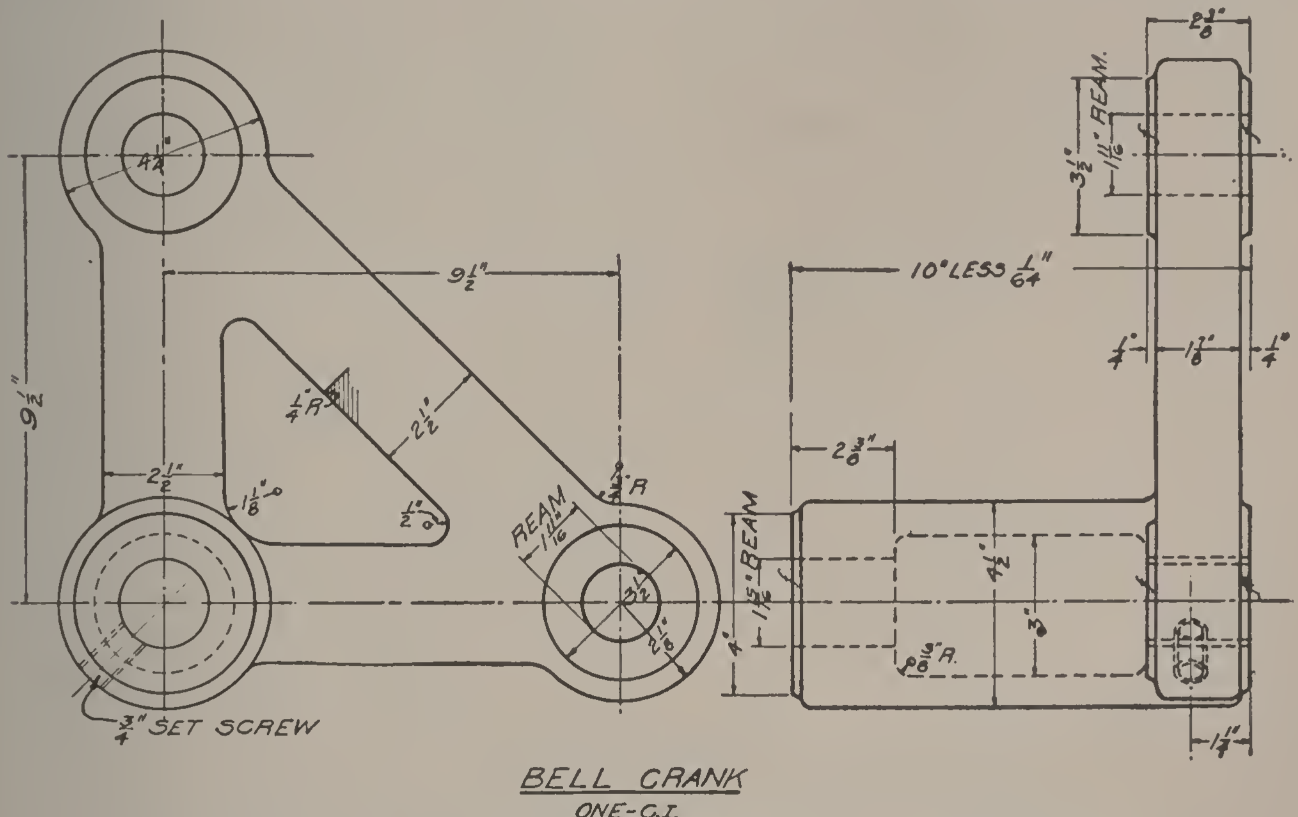


Fig. 33. Method of Showing Dimensions on Detail Drawing

the dimension is. The other method of stating this would be "9 $\frac{63}{64}$″", which is obviously a somewhat cumbersome and odd dimension; it is easier for the machinist to read 10″ on his scale and finish the distance $\frac{1}{64}$″ less, than it is to use the actual figure. This point is an instance in which the instructions furnished by the drawing to the workman are simplified for his benefit.

Another point worth noting in this figure is that circles are dimensioned by giving the diameters in preference to the radii; this is for the benefit of the pattern maker and the machinist, who always use calipers for measuring these parts. When the radii are given, the workman is forced to multiply the radius by two in order to secure the dimension for his calipers; and it is always better to

remove the chance of error on the part of the workman in the shop when making mathematical calculations. A detailed drawing should be so completely dimensioned that there will be no occasion for the workman to make any calculations himself; for, even if he is competent to do it, the responsibility for the correctness of the figures should be on the draftsman. In practically all shops the workmen are not allowed to scale the drawings in case dimensions are lacking, but are required to go to the drafting room and have further dimensions put on as required. A good detail drawing should require no such additions.

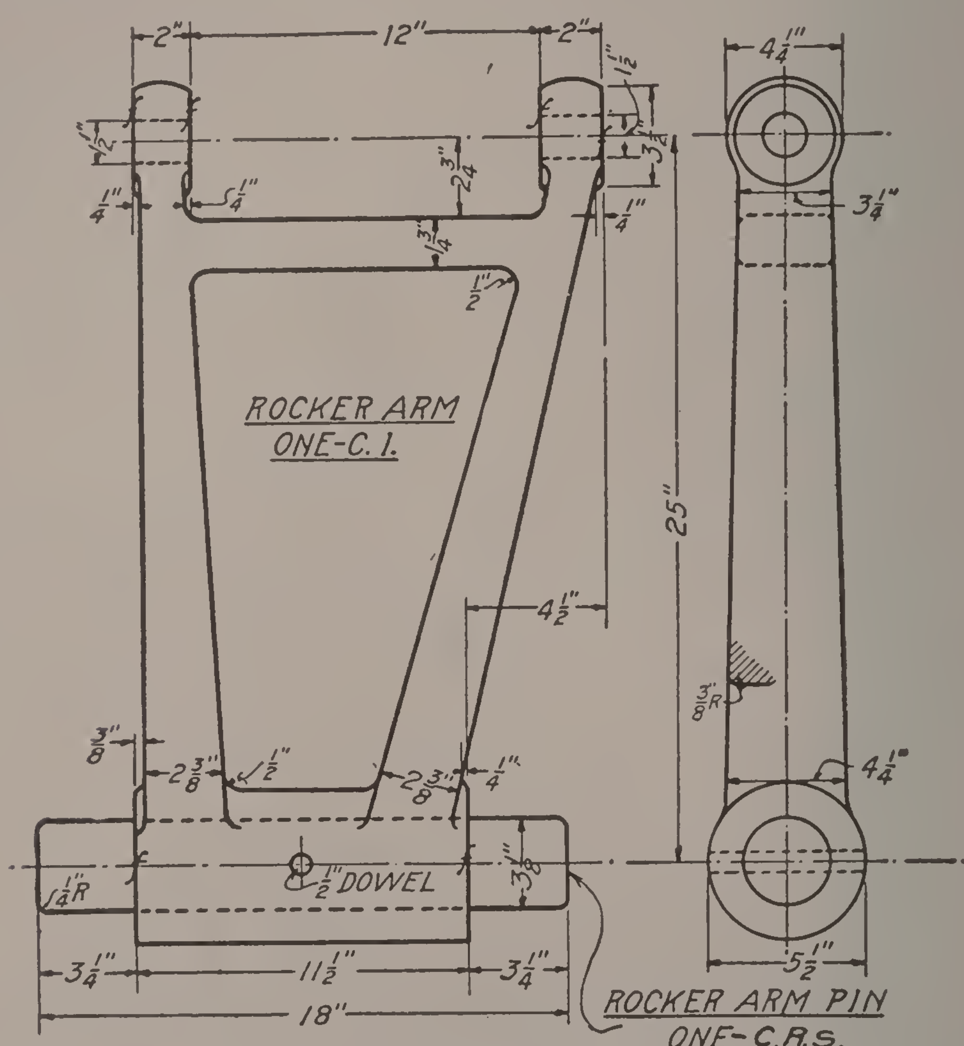


Fig. 34. Detail of Rocker Arm and Pin

Rocker Arm and Pin. Fig. 34 shows the detail of a rocker arm and pin, such as are frequently found in connection with the valve gear of a steam engine. This is a case where it is just as clear to detail two pieces together as to separate them entirely, the rocker arm pin being shown in position in the large hub and dimensioned in that position. This is not only simpler, but it gives the added information to the workman of just how the pin goes in the arm, and enables him to make his fits accordingly.

This principle of detailing several pieces together may, however, be carried to the point where the drawing becomes confused and complicated; then it is best to separate the detail of the parts. There are often special reasons requiring the detailing of parts of one kind on one sheet and of another kind on another sheet; for example, some shops detail forgings on one sheet, castings on another, parts to be made on the screw machine on another, and turret lathe work on another, etc. Such arrangements are, however, dependent upon the particular shop organization to which they apply.

Link Stud. Fig. 35 shows a link stud, also used in connection with the valve gear of an engine. On such pieces as this it is usually considered that they are finished all over unless otherwise mentioned. It is always desirable, in finished pieces of this character, to give the length *over-all* of the pieces, in order that the workman may quickly determine how much stock to order from the stock room without having to add up the figures between the various shoulders of the piece. The head of this stud is a hexagon, and the usual method of calling for the hexagon is given in the note, "2″ across flats". The reason the distance across flats is specified is to enable the workman to see at once what the necessary width of the jaws of the wrench must be in order to fit the head of the stud.

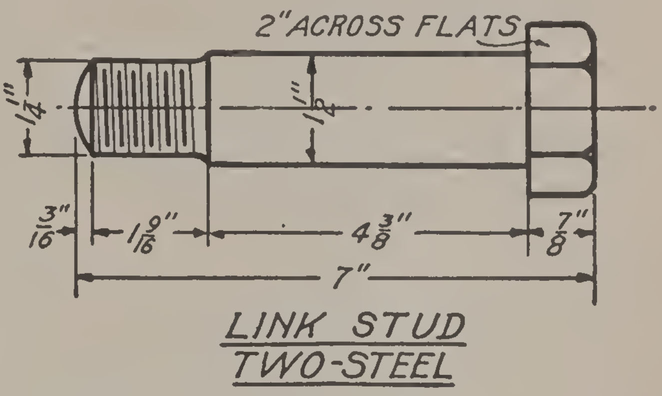
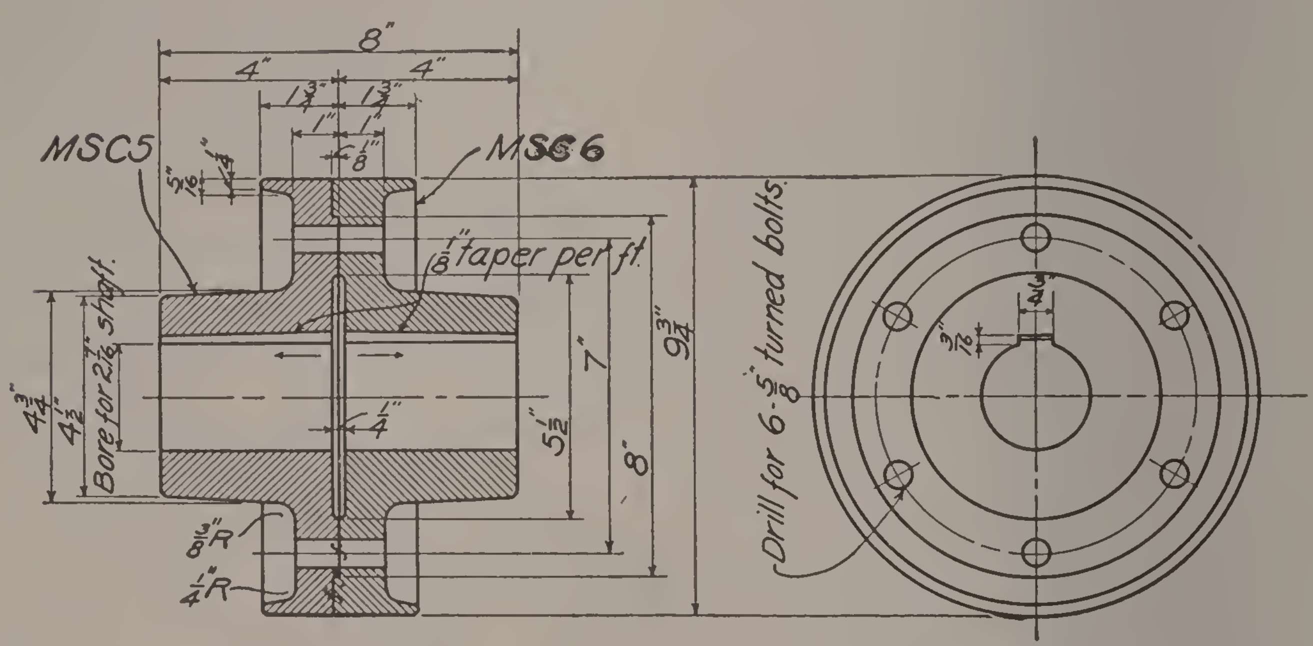


Fig. 35. Detail Drawing of Link Stud

Flange Coupling. Fig. 36 shows a flange coupling such as would be used to connect up a line shaft in a shop, or any heavy machinery shafting. The detail construction of this is most clearly shown by making the drawing in cross section. This drawing is a good illustration of the placing of the dimensions entirely outside the lines of the drawing, thus enabling any changes to be made in the figures without in any way obliterating the drawing. It also keeps both drawing and figures definite and clear, avoiding any possibility of confusion. Each half of the coupling is fastened to its shaft by a tapered key; and in order that it may be clearly understood which way the top of the keyway is tapered, the arrows,

shown in the cross-sectional view, indicate the direction in which the key is driven home.

Pattern Numbers. On this drawing are indicated the pattern numbers. They would be equally necessary on all other castings illustrated in this book; but for purposes of simplicity they have generally been omitted. Pattern numbers are necessary, not only that the patterns may be filed away systematically, and readily found when wanted, but also that the necessary orders for the castings may be written, and that the pieces may be identified on the drawings. For wrought-iron and steel pieces which have no patterns,



2 7/16" Flange Coupling - Steel Casting.
2 - Female - MSC 6. Ship with shaft MS17.
2 - Male - MSC 5. " " " MS18.

Fig. 36. Detail Drawing of a Coupling, Using a Cross-Sectional View

certain letters or numbers are given them, such that the identification is as complete as with castings. Castings, whenever possible, carry on their surface the pattern numbers in raised figures, and when received in the shop or field can thus be identified for assembling in the machine. Wrought-iron and steel pieces, which cannot have such figures raised upon them, are usually marked with painted letters and figures, to correspond with piece marks called for on the drawing, thus enabling them to be properly identified at the shop and in the field. There are many different systems in vogue for this numbering, dependent upon the particular requirements of the shop organization to which it applies.

Clamp Eye. Fig. 37 shows a piece designed to receive a threaded rod at one end and to clamp rigidly to a shaft by means of a bolt at the other. This detail, simple as it appears, is awkward to make, on account of the bolt boss being at an angle with the principal center lines. The lower view is a cross section, because, if the ordinary elevation were shown, it would have a series of ellipses showing the bolt boss projections. It is always desirable to avoid oblique projections of circular shapes on account of the difficulty of drawing same; moreover, the ellipses produced do not show the

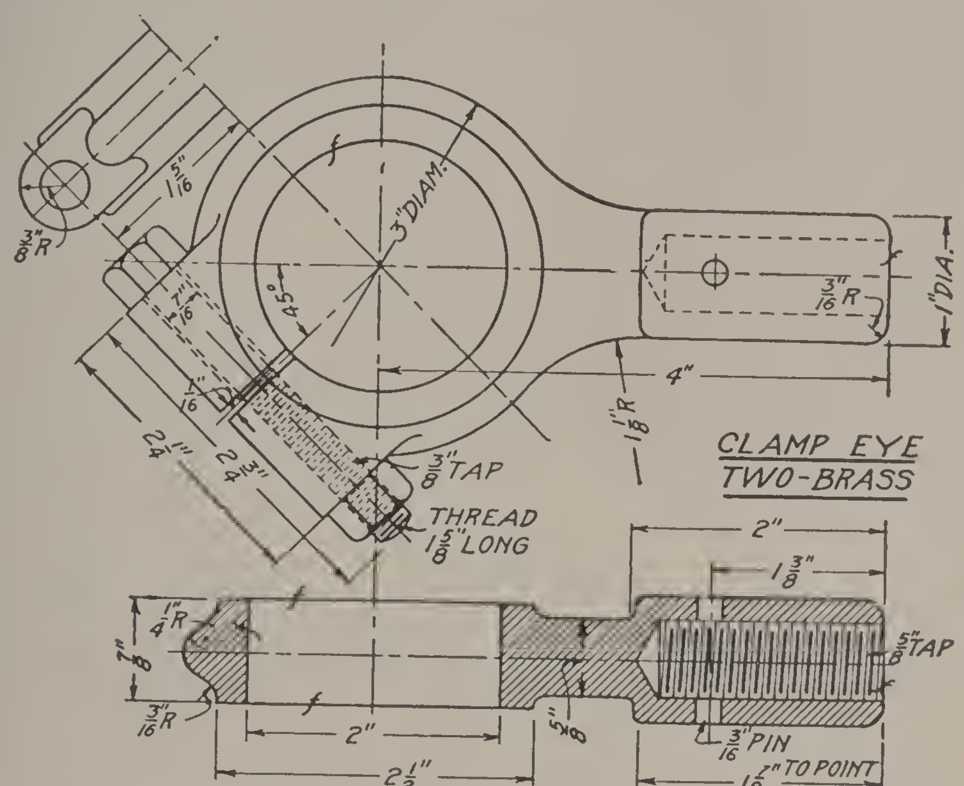


Fig. 37. Detail Drawing with a Projection Thrown Off at an Angle with the Principal Center Lines

construction as plainly as a straight projection. The method adopted in such cases is to throw off a straight projection at the same angle as the part in question makes with the principal center lines. In the present instance it is necessary to show that the boss for the bolt is $\frac{3}{8}''$ radius, and that the boss is centrally located with the hub, which is readily done by the straight projection thrown off. In the cross-sectional view, the lines representing the thread appear to the eye sloped in the wrong direction, or as though the thread were left-hand. A moment's thought, however, will convince the student that, since the section taken is through the middle of the hole, we are merely looking at the back side of the hole, and that the threads of a right handed screw on the back side must necessarily slope in the direction as shown. In the case of the thread on

the bolt for the clamping hub, shown dotted, the lines of the thread appear right-handed to the eye, it being universal practice in the case of dotted threads to show the side only next the eye. If the threads on the back side of the bolt were also shown, they would slope in the other direction, crossing the other lines, and to draw them in would obviously cause confusion.

Connecting Rod. Fig. 38 shows the connecting rod for a small steam engine. This piece calls for little comment. The outlines of the crank pin and cross-head pin are shown in dot-and-dash circles, and the relation of these centers to the rod is given. This is of some importance in enabling the detail of the boxes, which go in the heads of the connecting rod, to be correctly detailed and checked. It

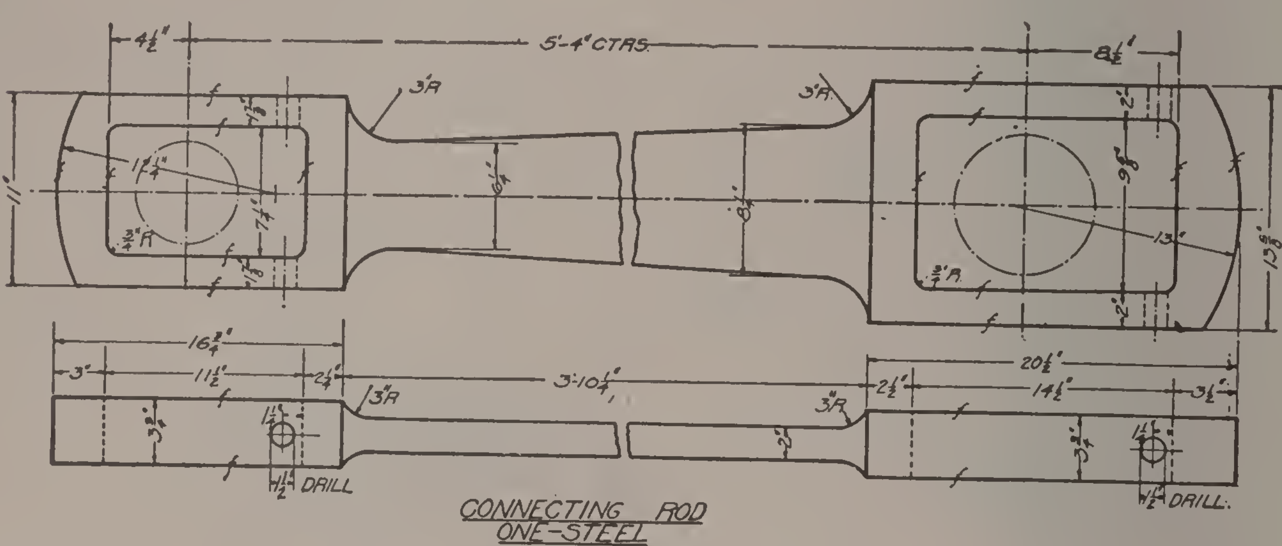


Fig. 38. Detail of a Connecting Rod

should be carefully noted by the student, that any such information which can be given on the details, without confusing the drawing, to tie up one detail with another, is usually good practice. It not only saves time in the drafting room in checking and general reference work, but it gives the workman a better idea of how the parts are expected to go together, thus fulfilling the general definition of a working drawing as "complete and definite instruction".

Gear with Split Hub. *Conventional Drawing.* Fig. 39 shows a gear with a split hub, the bolts through the hub being for the purpose of tightly clamping same to the shaft. This is an illustration of the conventional method of showing a gear with standard proportions of teeth. If the drawing were made exactly as the gear would look, it would be necessary to spend a large amount of time inking in the outlines of the 72 teeth around the circumference of the gear;

instead of doing this, the pitch line of the gear is shown, and circles drawn indicating the top and bottom of the teeth. The pitch diameter and outside diameter are given, and the proper depth of tooth cut to be made by the gear cutter; nothing more is necessary.

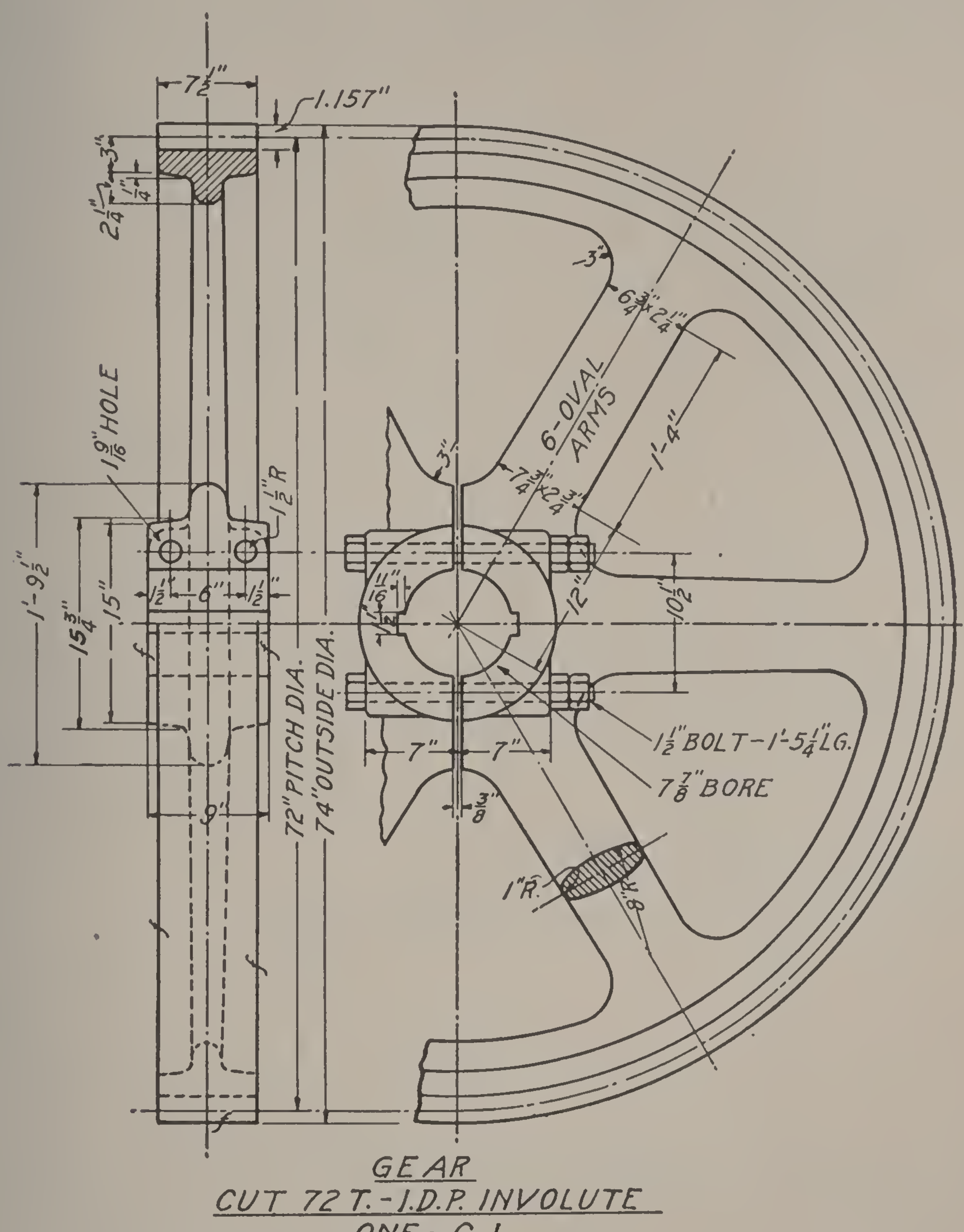


Fig. 39. Detail of Gear with Split Hub

The information which enables the workman to choose the proper cutter is given in the title; thus, "Cut 72 Teeth—1 Diametral Pitch —Involute." The workman will receive from the tool room a standard involute cutter marked for 72 teeth, 1 diametral pitch. After placing same on the arbor of the gear-cutting machine, he will drop the cutter into the gear blank to the depth called for by the drawing;

if this is accurately done, it will give the desired standard thickness and clearance of the teeth, and the automatic indexing of the machine will produce the 72 teeth, accurately spaced. If the gear were a cast gear—in which case the pattern maker would have to lay out the teeth and finish them one by one on the pattern—it would be necessary to draw one or two teeth on the circumference of the gear,

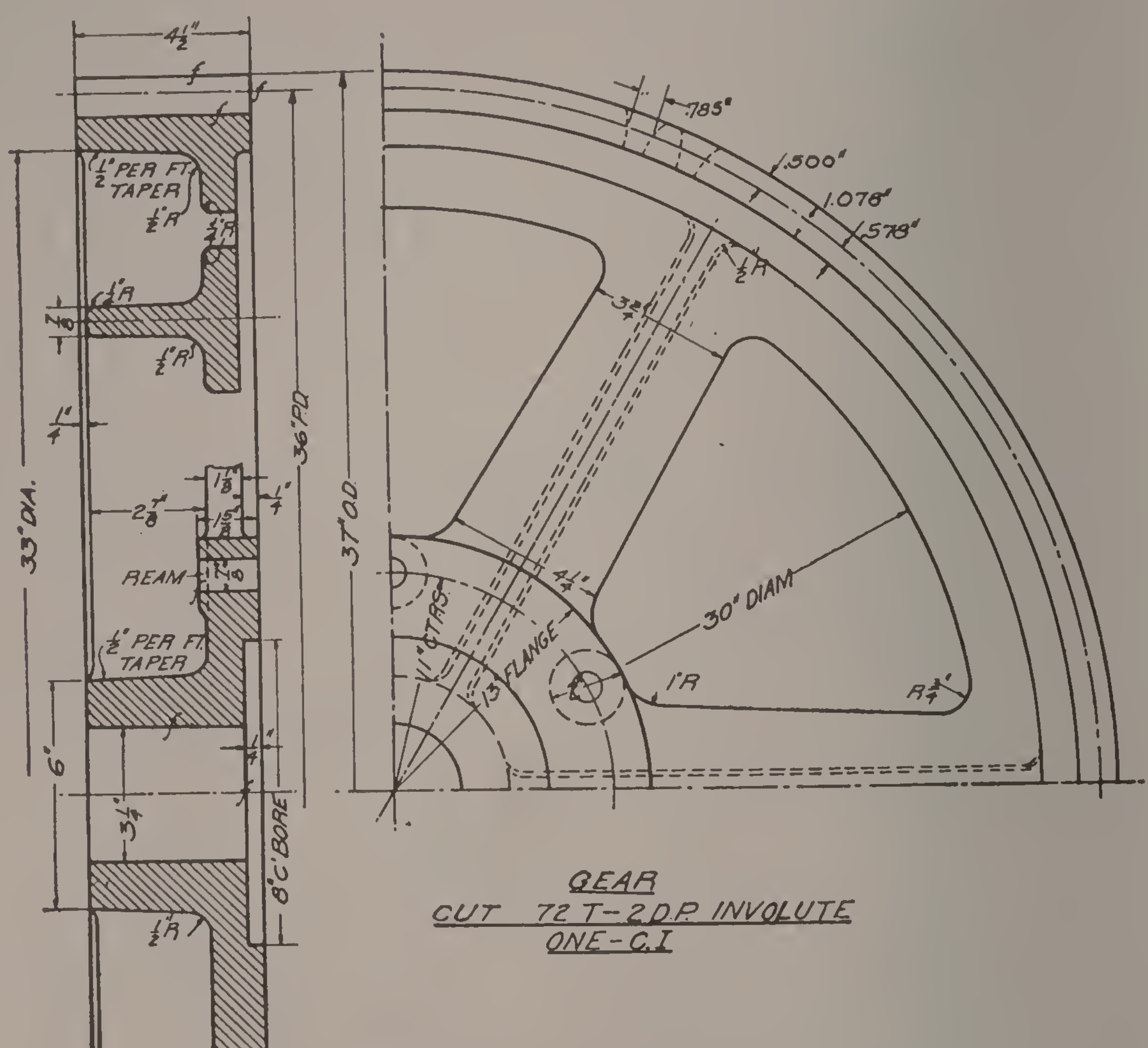


Fig. 40. Detail of Gear with Solid Hub

and give sufficient figures to enable him to lay out the teeth either by his dividers or by a template. In neither case, however, should the detail draftsman take the time to draw the teeth in any great number around the circumference of the gear; this is a very common thing for the young draftsman to do, and nothing shows his greenness more. He should bear in mind that when the proper instruction has been conveyed by his drawing, any more time spent on it is wasteful.

Cross Section. The cross section of the gear is shown to enable the necessary figures to be placed upon the rim and hub. In the

right-hand view, only one-half the complete circle of the gear is shown; nothing would be gained by showing the other half, therefore it would be a waste of time and space on the drawing to make it.

Attention is called to the method of indicating the dimensions of the arms, the breadth and thickness of the oval being indicated as follows: “6$\frac{3}{4}$″ × 2$\frac{1}{4}$″”; this is a “short cut” which will usually answer, but it does not actually show the section of the arm. It would be better actually to make a cross section, as shown in the lower portion of the right-hand view, giving the actual radii for the section, as otherwise the pattern maker might make an arm more or less blunt on the ends than the draftsman intended.

Spur Gear. Fig. 40 shows the detail of a spur gear with a T-shape arm. The gear drives through fitted bolts in the flange about the hub. Two or three teeth are dotted in, to show their dimensions, which are according to the standard involute system.

Pinion for Spur Gear. Fig. 41 shows the detail of a pinion designed to mesh with the gear in Fig. 40, one view being sufficient.

Pair of Beveled Gears. Fig. 42 shows the detail drawing of a pair of bevel gears. By careful study of this drawing, the student will gain an idea of the dimensions to be shown on a bevel gear.

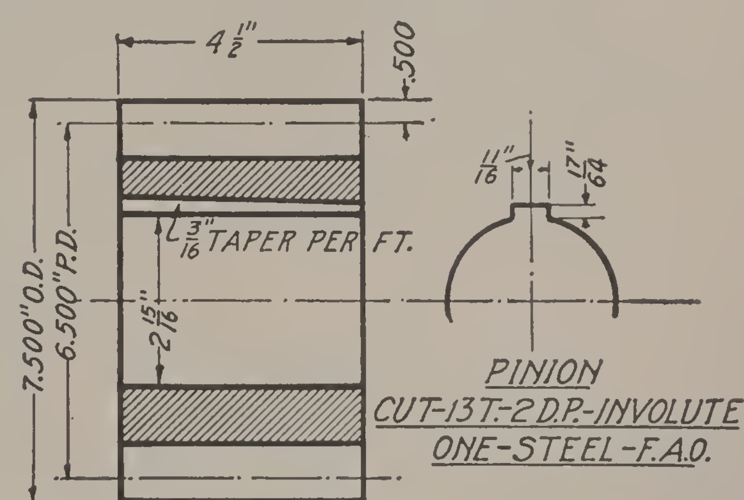


Fig. 41. Detail of Pinion to Mesh with Gear of Fig. 40

The gear-cutting machines, on which the teeth of these gears are cut, require the angles as given for the setting of the cutters. It should also be remembered that the casting must be finished by the machinist before the teeth are cut; hence the dimensions for hubs, diameters, etc., must be so put on that they can be conveniently used by the machinist in turning up the gear blank in an ordinary lathe.

Worm and Worm Gear. Fig. 43 shows the detail of a worm and worm gear. The teeth on the worm gear are twisted; and if it were attempted to show their true projection, it would be a complicated and difficult piece of work. The worm gear is shown, therefore, by drawing the pitch line of the teeth and other circles at the

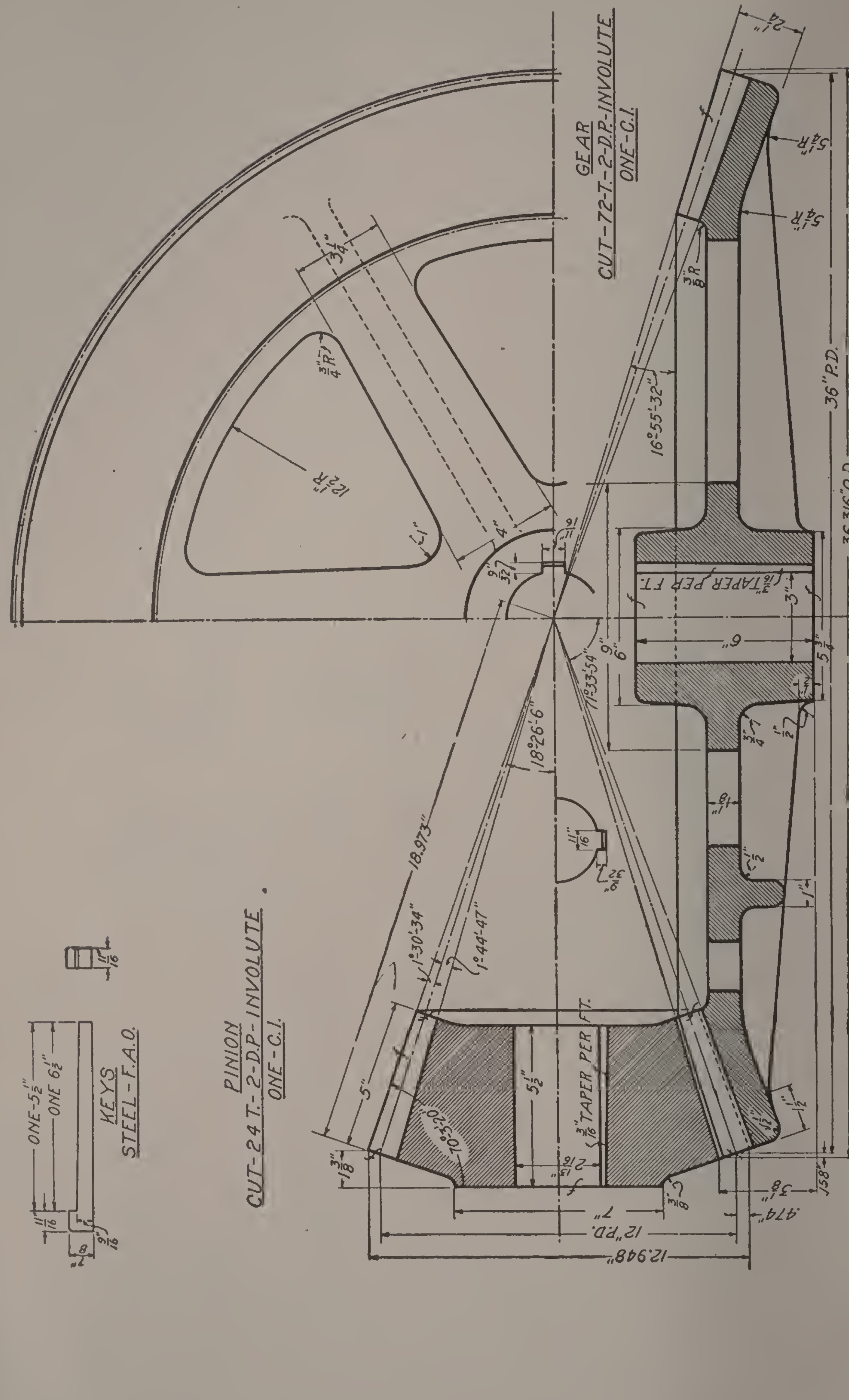


Fig. 42. Detail of Bevel Gear and Pinion

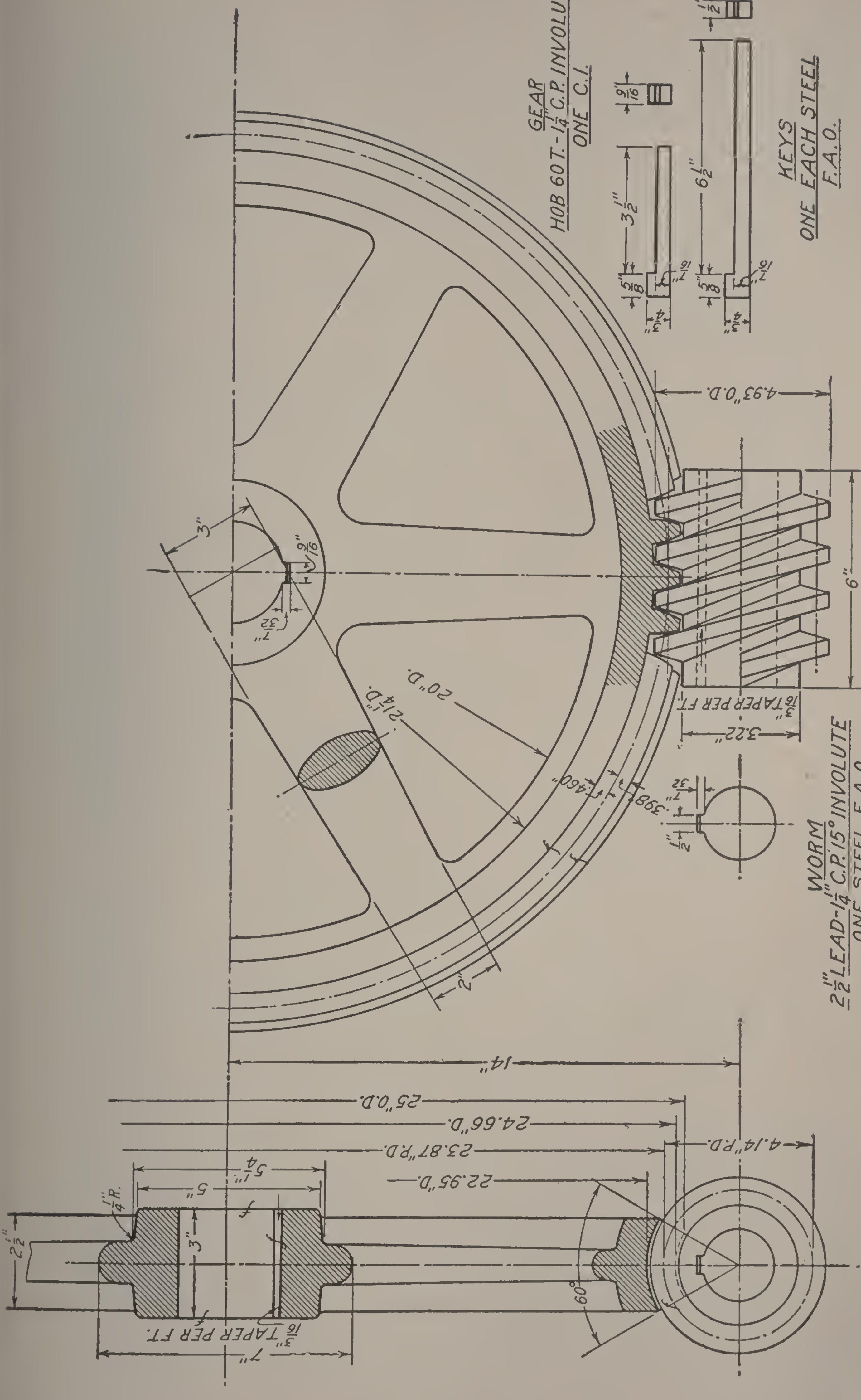


Fig. 43. Detail of Worm and Worm Gear

top and bottom of the teeth. At the point where the gear is in mesh with the worm, a portion of the rim is broken away, and the middle section shown. The worm threads, which are lines in the form of helices, are shown in the drawing merely by straight lines, this being the conventional way for representations of this character. Another way of showing the worm would be in cross section, in which case the helical lines would be wholly avoided; as drawn, however, it has the advantage of at once conveying to the eye that it is a right-handed thread.

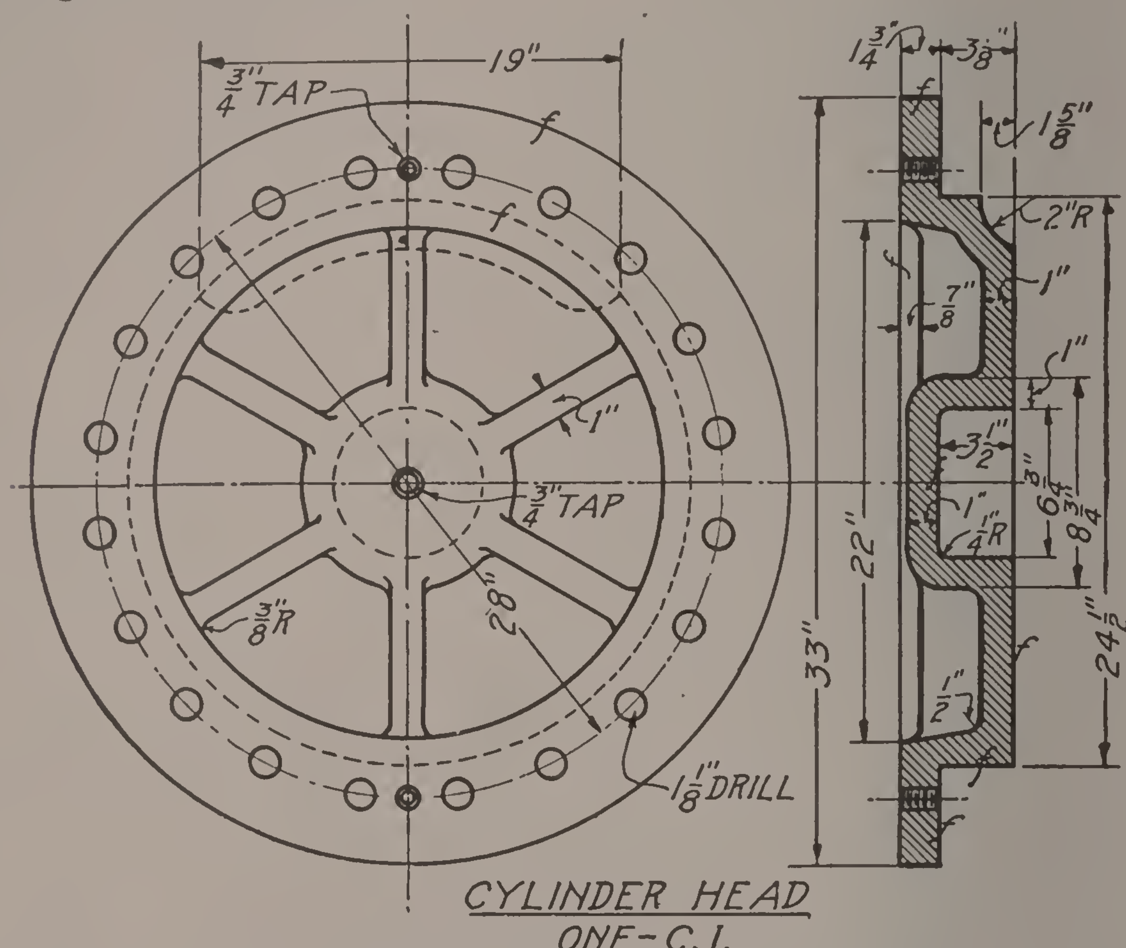


Fig. 44. Detail of Cylinder Head of Steam Engine

Cylinder Head. Fig. 44 shows the cylinder head of a steam engine. Although in the drawing the entire circle is shown, it would have been just as clear if only one-half had been shown, similar to the manner of showing the side views of the gears just discussed. In the plan view, it should be noted that the tapped holes are indicated by double circles, while the drilled holes show a single circle. The inner circle for the tapped holes is intended to represent the bottom of the thread, while the outer circle represents the top of the thread. Another conventional method for a tapped hole is to fill in the circle entirely with black ink; the method illustrated, however, is the most common.

Water Cylinder for Triplex Pump. Fig. 45 shows a water cylinder for a triplex pump, and is an excellent illustration of many of the points heretofore brought out, combined on a single drawing. This drawing should be carefully studied in detail. Note the general boldness of the lines, and the sharp contrast between the full-line work and the center, dimension, and dotted lines. Note that in the

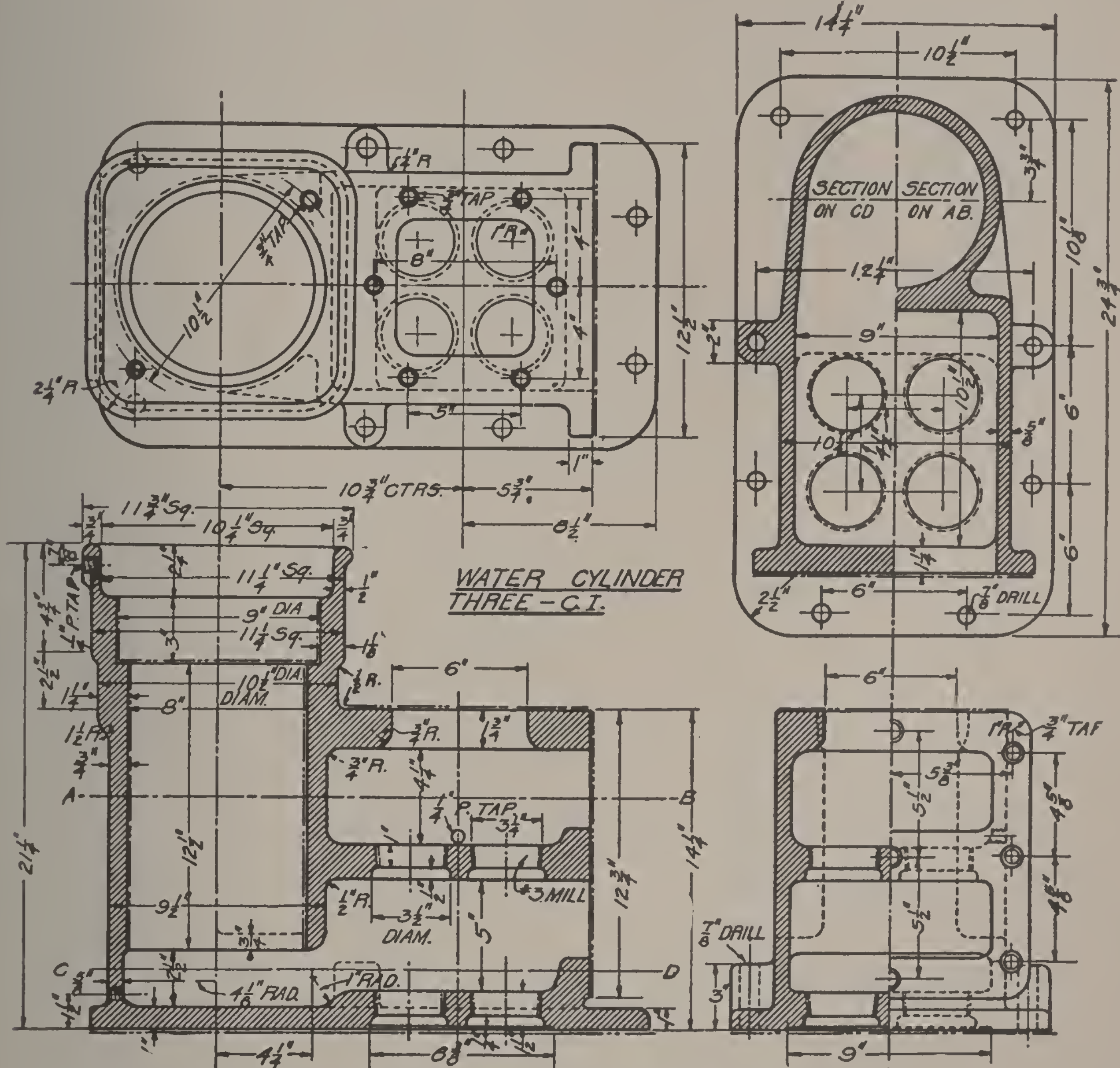


Fig. 45. Detail of Water Cylinder for Triplex Pump

cross-sectional views the dotted lines have been almost entirely eliminated, thereby leaving the section work clear and plain. There is no necessity of showing parts in dotted lines which are beyond the plane of the section, but in several places just enough simple dotted work is shown to convey the relation of the parts.

Object of Each View. Each sectional view is made for a specific purpose, and that purpose is never allowed to be obscured. The top plan is mainly to show the upper portion of the water cyl-

inder; the cross section below it gives the principal interior view; the right-hand half-elevation and cross section are for the purpose of showing the face of the valve chamber and the interior of the valve chamber; the horizontal cross section in the upper right-hand corner of the drawing shows not only the interior of the barrel and valve chamber at two different points, but also a clear outline of the base of the entire casting. Each view must be used with the other to get a clear idea of the construction; but each view is so simple in itself that no confusion arises in the mind as to what its lines mean; one view is readily associated with the other, and the grouping of the four views is such that the eye passes easily over all of them.

Method of Grouping Dimensions. Note the grouping of the dimensions, following in general the purposes of each of the views as explained above. On the top plan are given the dimensions affecting the top of the casting only. On the principal vertical cross section are given the greater part of the dimensions for the entire piece. This is as it should be, for the dimensions should always be grouped as much as possible on the principal view of an object, provided they can be clearly put on that view and not become so numerous as to cause confusion. A drawing over which the eye has to wander widely in search of the several dimensions of the same portion, is slow and difficult to read. On the right-hand half-elevation and cross section are the figures for the outline of the face of the valve chamber, and the location of the tapped holes for the hand-hole cover-bolts. On the horizontal cross section are given the figures for the interior dimensions of the valve chamber, and a complete dimensioning of the base of the casting. The special attention of the student is called to this systematic grouping of the dimensions on the view which will most clearly show them. A glance at this drawing is sufficient to suggest what a confusion of figures there would have been, had it been attempted to place them all on two views, and if, instead of cross sections, full and dotted lines had been used.

Method of Showing Finished Surfaces. On this drawing is indicated a new method of showing finished surfaces. Each surface which is intended to be finished in the machine shop, has drawn next to it a medium-weight line consisting of a long dash and two dots. This method of showing finished surfaces is not as common as the

one heretofore used, of writing the letter *f* across the line; it has the advantage, however, of conveying an absolutely definite idea of the extent of the surface to be finished, and in some instances is especially valuable on this account. It is a good way of specifying the finish; but for general practice the letter *f* is simpler and perhaps more readily and universally understood.

Analysis of Drawing. This drawing, while not complicated, contains quite a large number of dimensions, and is a good example of the principle of systematic figuring. The student's attention, therefore, is called to the following analysis of the dimensions on the drawing.

The casting consists of a barrel, in which the plunger slides, with a stuffing box at the top and a waterway at the bottom leading into the valve chamber; attached to this barrel is the valve chamber, consisting of two compartments, the lower one for suction, the upper one for discharge; to support both barrel and valve chamber and permit of their being bolted to the water-supply casting, a rectangular base is provided.

Beginning at the top of the casting, the figures for the stuffing box, inside and outside dimensions and thicknesses are given, and note made that the outline is square. The tapped holes for the gland studs, and bosses for the drips, are shown most clearly in the top plan, and are therefore dimensioned there. Next we come to the bore of the barrel to receive the plunger, and here the square shape of the casting changes to a round, the diameter and thickness of metal being given. Below this cylindrical part is the waterway, the height of which ($2\frac{1}{2}''$) is given, and then the $1''$ thickness of the base below. This completes practically all the dimensions of the barrel and stuffing box.

Passing to the valve chamber, it is first necessary to locate the center line of same in reference to the barrel ($10\frac{3}{4}''$ centers). This being done, the arrangement of valves is dimensioned, and figures given for the valve chambers, thus—length, breadth, depth, thickness of metal, fillets, etc.; then follow the location of the face of the valve chamber, $5\frac{3}{4}''$ from the center line, and the layout for the handhole cover; then the location of the upper face of the valve chamber, $14\frac{1}{4}''$ from the base, and the layout for the flange of the discharge pipe, which is shown on the top plan.

Few figures as yet have been placed on the base of the water cylinder; these are now completed by starting at one side of the base and going completely around same, giving not only external dimensions and radii, but also location of bolt-holes and their sizes—all of which are shown in the horizontal section.

This completes the dimensions; and if the student has carefully adhered to each particular part of the casting until completely dimensioned, and has not passed in haphazard fashion from one portion of the casting to another, he will have succeeded in dimensioning the piece with absolute completeness. No part will have escaped being dimensioned, and no part will be dimensioned twice. It would be a good plan for the student to copy this drawing, using a scale of 3 inches to the foot, and, in making the drawing, to follow the description as given above in reading the figures from the cut. He will thus more clearly realize the systematic progress from one part of the casting to the other, and will himself check the figures shown.

Hoisting Drum. Fig. 46 shows the detail of a hoisting drum to carry wire rope. Attention is called in this detail to the enlarged cross section of the rim, conveniently placed to show clearly the style of the groove. It should also be noted, that, instead of drawing the grooves the entire length of the drum, but a few are drawn at each end of the drum and a note placed against same to indicate that the grooves are to be cut the entire length. This is another "short cut" consistent with the definition of a working drawing. The breaking away of a portion of a view is illustrated in the right-hand elevation, in which a small section is exposed to show the method of fastening the end of the wire rope.

Crane Drum Grooved for Chain. Fig. 47 shows a crane drum, grooved for chain, and carrying its driving gear and shaft. This is a very good illustration of the economy of grouping parts together, instead of detailing them separately. It is obvious that the drawing of each detail is just as clear as though it were separately drawn. In fact, the information conveyed is the most complete possible; for not only are the figures for each part clearly shown, but the exact manner in which the parts go together, thus enabling the workman to understand at a glance the assembling of the parts, and to make his fits accordingly. A general drawing for this purpose alone has

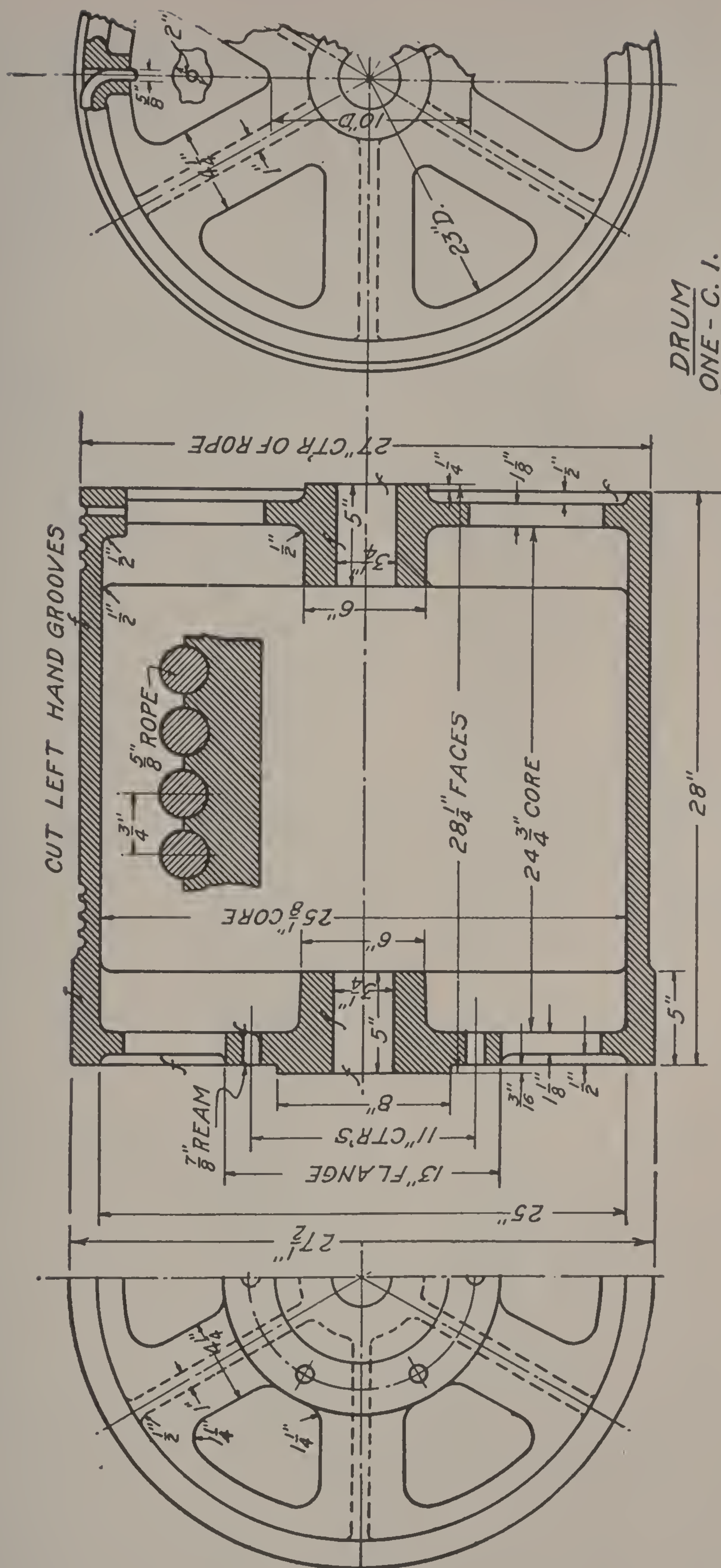


Fig. 46. Detail of Hoisting Drum to Carry Wire Rope

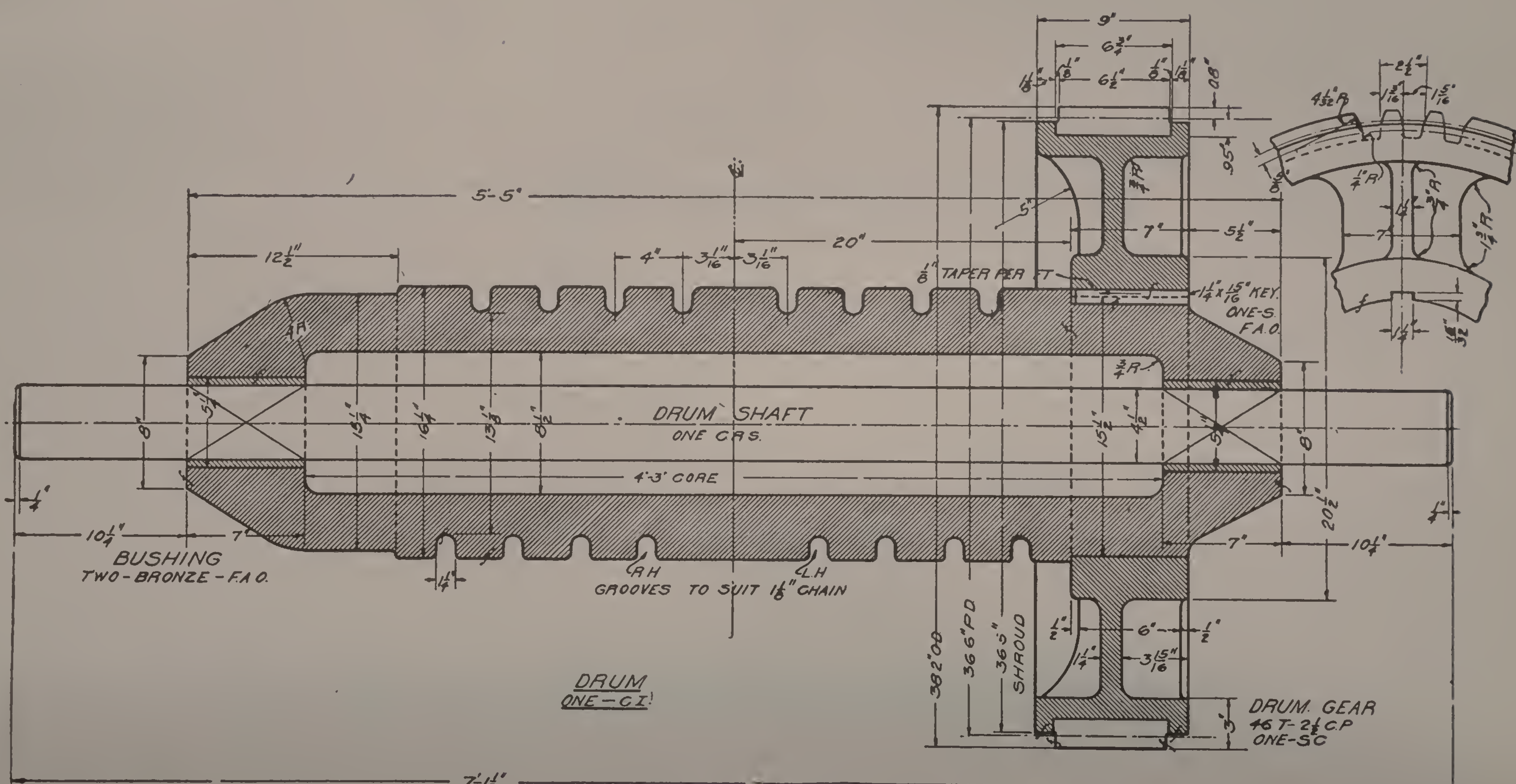


Fig. 47. Detail of Crane Drum

to be made in the case of a complicated machine; and it would be confusing to put on such a drawing figures sufficient to detail each part. The draftsman who can properly judge when to use assembled drawings for detail dimensions, and when to avoid such use, will save a large amount of time and money in the production of drawings for shop use. A common rule that "every part shall be detailed separately" is in vogue in many drafting rooms; but it is seldom followed literally, and when so followed becomes a drag on office efficiency. A better rule is—"Detail every part separately when groups of parts cannot be clearly detailed together."

Note on this drawing the method of indicating, by light diagonal lines across the shaft, the location of the bearings; also the enlarged view of a few teeth of the gears, with sufficient figures for the pattern maker to work out the teeth. These gears are "half-shrouded", or strengthened by a rim extending up to the pitch line.

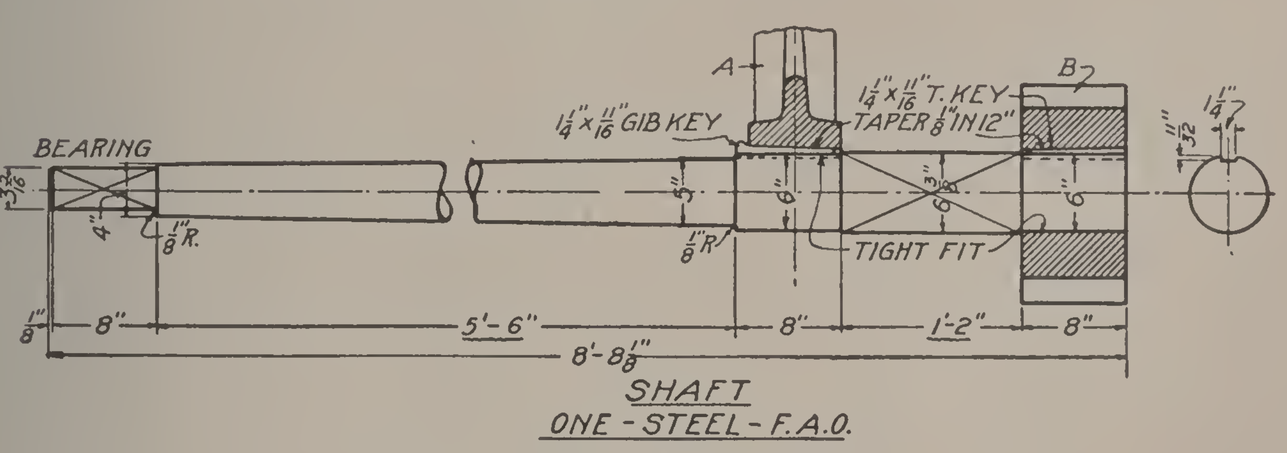


Fig. 48. Detail of an Ordinary Shaft

Detail of Ordinary Shaft. Fig. 48 shows the detail of an ordinary shaft with a number of different bearings and fits upon it. It illustrates most of the common points which are necessary to be specified on shaft details. The distance, shoulder to shoulder, is usually given throughout the entire length of the shaft, and these distances summed up for the "over-all" dimension. The "over-all" dimension is important, because from it the stock is ordered and cut off; and the workman should not be required to add up a lot of figures to secure it. Fillets should be allowed at every shoulder, if possible, and their radius specified; in this way there is less liability to the formation of incipient cracks than if the corners are left sharp. Keyways should be carefully dimensioned and located. Bearings should be indicated by light lines running across the shaft diagon-

ally; and it is good practice to print the name of each piece to which the shaft is fitted, just above the shaft at the point where such fit occurs, or the parts themselves are partially shown in light lines, as at *A* and *B* in the figure, thus enabling the workman to make the fits more intelligently. It is common practice to make all holes which receive shafts of exactly "gauge diameter", and to make the allowance for the fit in the shaft. For example, a "3″ running fit" would mean that the hole in the piece to receive the shaft would be exactly 3″ in diameter, while the shaft would be, say, "3″ less .003″". Sometimes this allowance is indicated by giving the actual number of thousandths of an inch under size, as noted; sometimes by calling for a "running fit", or a "wringing fit", or a "pressed fit", or a "drive fit", or a "tight fit", as desired.

"Broken" Pieces and "Out-of-Scale" Dimensions. Shafts are often so long that it is difficult to represent their entire length on the sheet to the scale chosen. They are then "broken", as shown in the figure, and crowded up to a shorter length, the dimensions being depended upon to give the proper relation of the parts.

When there is occasion, because of some change, to alter a dimension on a finished drawing, it is usually permissable to change the dimensions without rubbing out the lines of the drawing, provided that no considerable number of other dimensions are affected, and provided that some sign or note is made on the drawing, calling attention to the fact that the dimension has been changed and that the drawing is "out of scale". Sometimes the dimension is placed in a circle thus 6″ or a line drawn beneath it thus, 6″; or the words "out of scale" placed after it thus, 6″ (out of scale). Although workmen are not allowed to "scale" drawings, yet it is dangerous to have dimensions which are out of scale on the drawings unless special attention is called to that fact.

The above remarks on "broken" pieces and "out-of-scale" dimensions are equally applicable to all details as to shafts, the points merely being illustrated by the figure under discussion.

Bearing Stand with Cap and Boxes Removed. Fig. 49 shows a bearing stand with the cap and boxes removed. There is little of special note to discuss in regard to this, beyond calling attention to the general nature and type of the piece illustrated. The design is characteristic of pedestals and bearings found about stationary

engines of large size. Such parts are usually massive and heavy in their proportions, with well-rounded corners and smooth outline. The closed-box form of casting affords maximum strength with good distribution of material, and at the same time conveys to the eye the effect of a solid piece throughout.

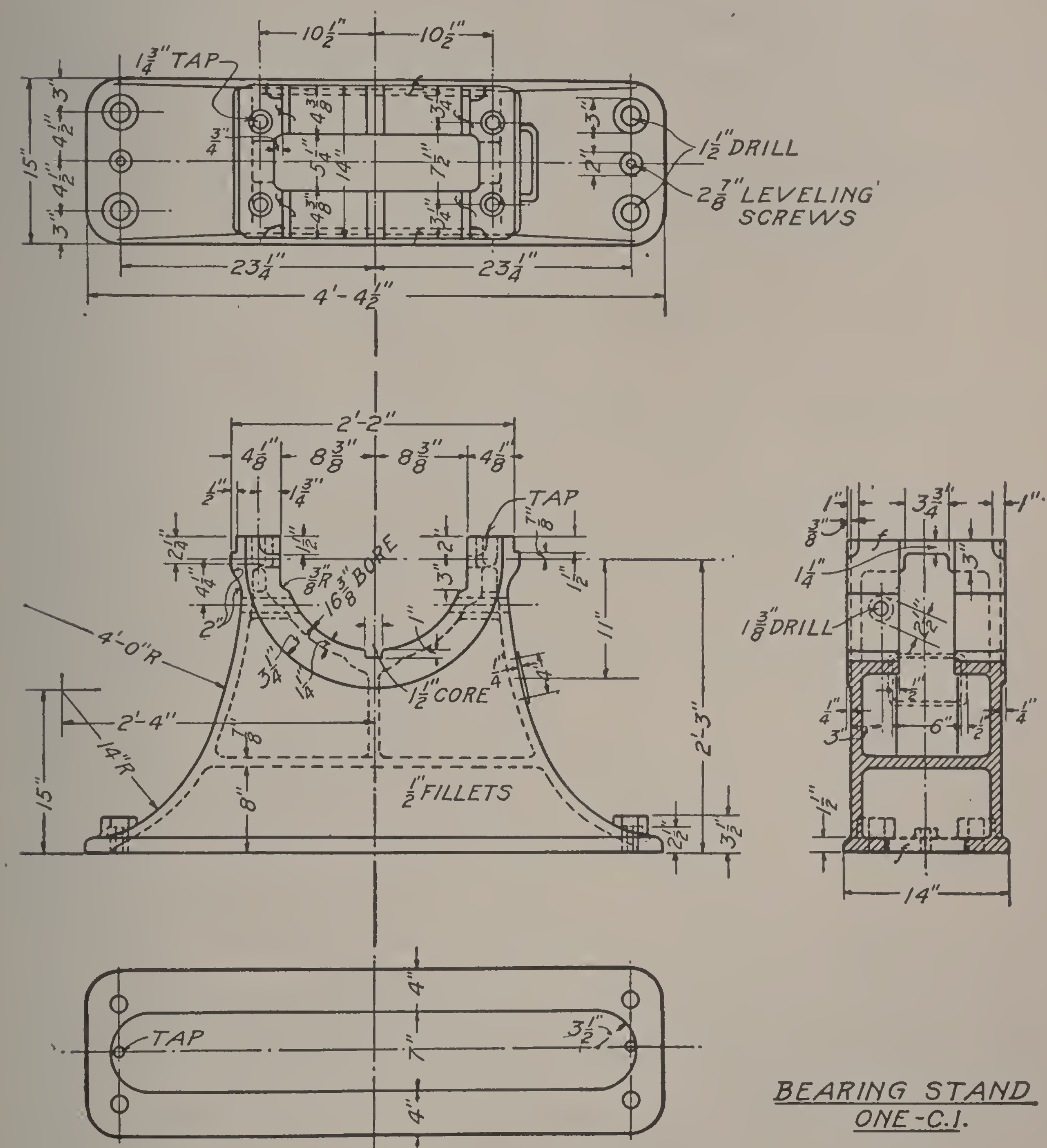


Fig. 49. Detail of Bearing Stand with Cap and Boxes Removed

Sample Letters. Fig. 50 shows a sample sheet of plain letters, such as are particularly applicable to working drawings. They are especially devised for easy, quick, and uniform strokes. Each draftsman has a character of his own in lettering and figuring, and the form of lettering which is most natural for him to use is the one

he will use to best advantage. It is necessary, however, to confine draftsmen to a general type in order to make their work reasonably uniform; and the sample sheet (Fig. 50) represents not only the most common type in use, but a type to which almost any draftsman can readily train his eye and hand. Whether the slopes are forward

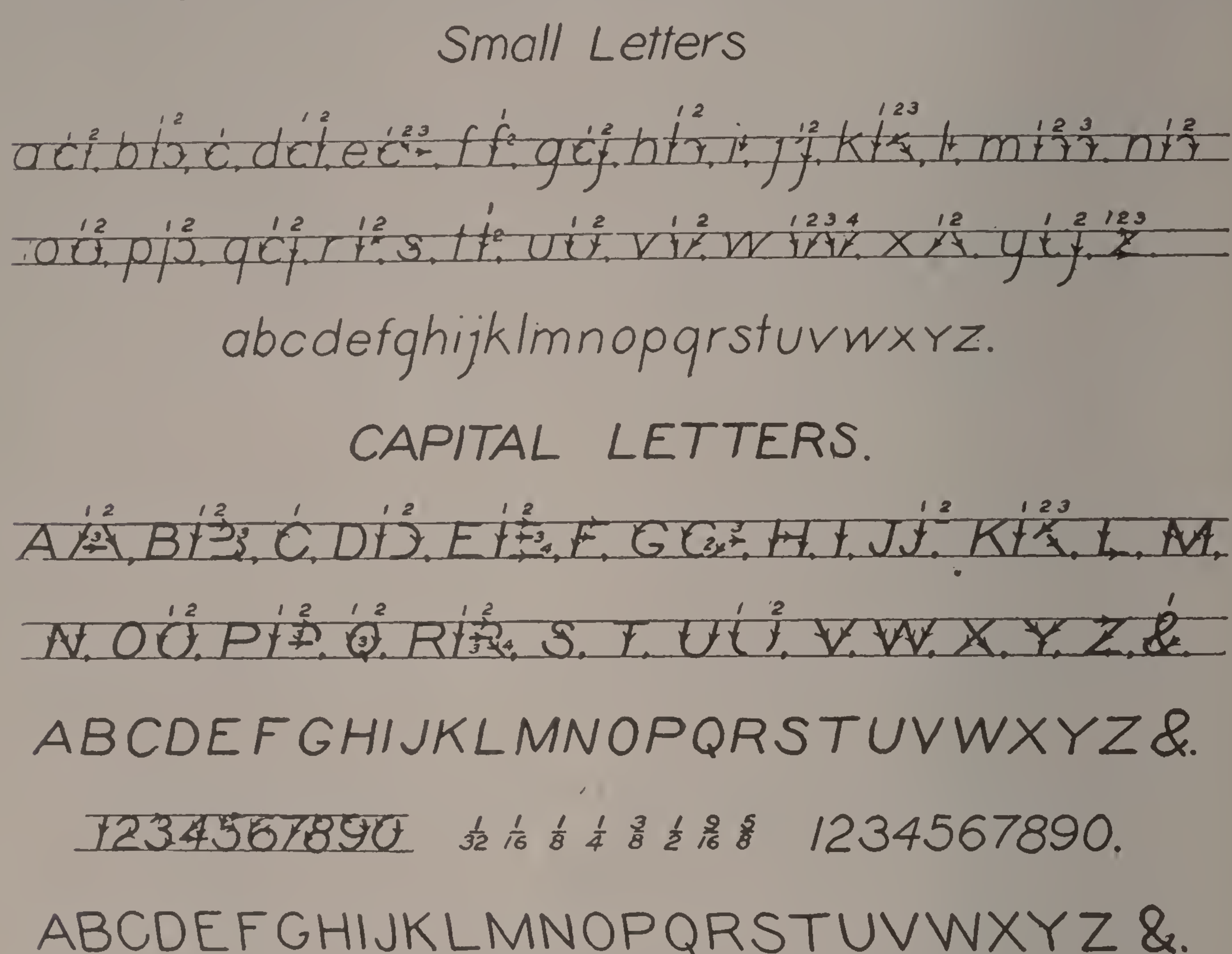


Fig. 50. Sample Sheet of Plain Letters Used in Working Drawings

or backward, or straight up and down, is of little importance, as long as the general style is maintained.

Drawing Room Practice. Every drafting room has certain methods and rules peculiar to its own organization and that of the shop to which it supplies drawings. While it is impossible to formulate any set of instructions which will cover all situations, the accompanying sheet, "Drawing Room Practice," is consistent with general practice in modern drawing offices and the fundamental principles discussed elsewhere in this book. It is a condensed code of procedure which the student will do well to hang in some convenient location near his table, and to consult freely as he works. It should not take the place of the explicit discussions of the text, but should be used as an index to it and as a reminder.

DRAWING ROOM PRACTICE

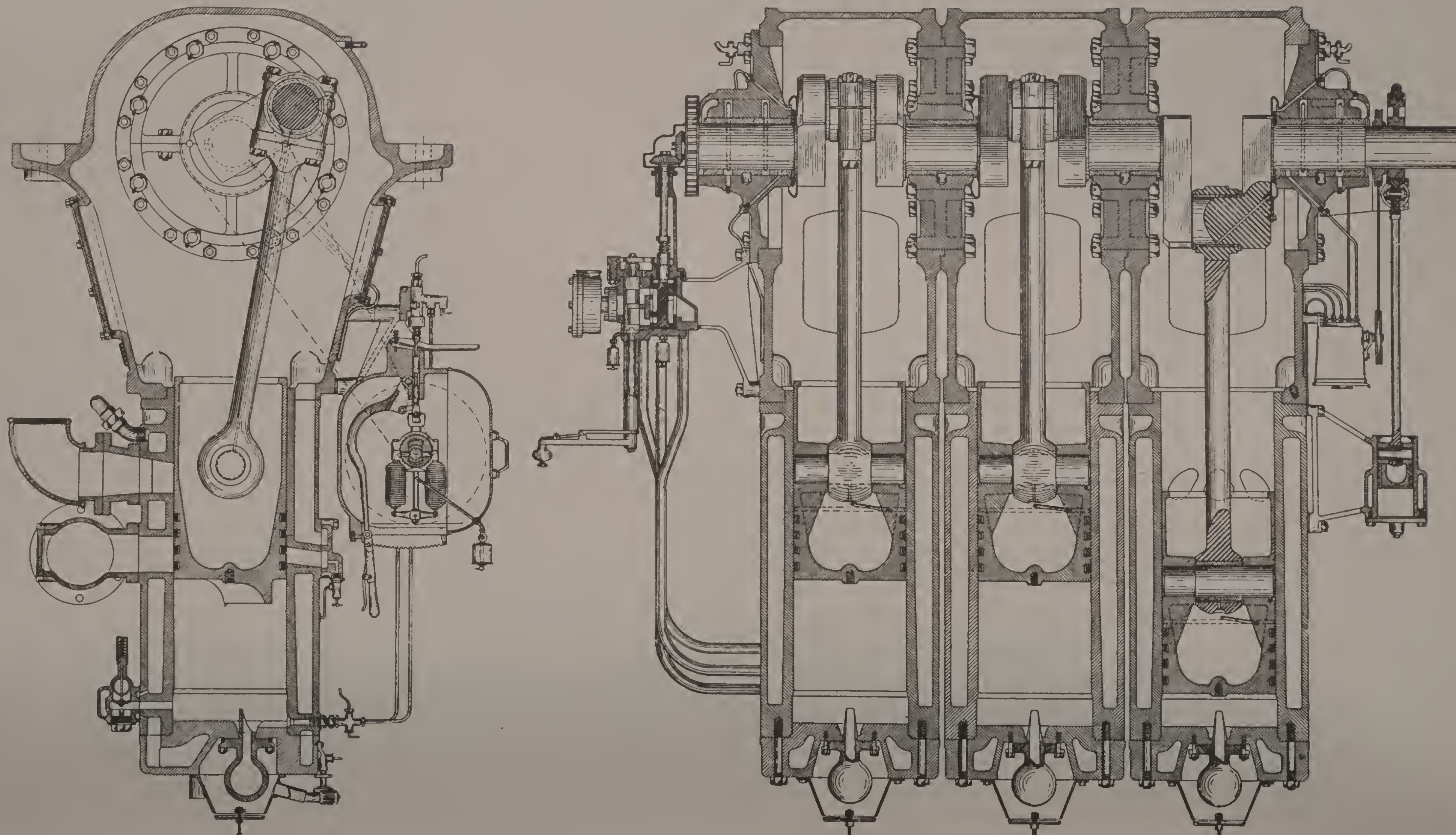
CHICAGO — AMERICAN SCHOOL OF CORRESPONDENCE — ILLINOIS

STD. SIZES	TRIMMING SIZE	TITLE FRAME	
PLATES	9"×12"	1"×2"	
	12"×18"	1"×2"	
DRAWINGS	18"×24"	$2\frac{1}{2}$"×4"	
	24"×36"	$2\frac{1}{2}$"×4"	
MARGINS	ALL MARGINS $\frac{1}{2}$" WIDE		
SCALES	USE THESE SCALES IN PREFERENCE TO OTHERS		
	12"=1' FULL SIZE		
	6"=1' HALF "		
	3"=1' QUARTER "		
	$1\frac{1}{2}$"=1' EIGHTH "		

CYLINDER
FOR
12×36 CORLISS ENGINE
AMERICAN SCHOOL OF CORRESPONDENCE
CHICAGO ILLINOIS
SCALE 3"=1' JULY 7, 1913.
C.L.G.

(SAMPLE TITLE)

	CHOOSE LARGEST SCALE CONSISTENT WITH SIZE OF SHEET.
PROJECTION	USE SIMPLE PROJECTIONS ONLY.
	MAKE VIEWS TO COMPLETELY ILLUSTRATE. NO MORE—NO LESS!
	PLACE VIEWS ON SHEET IN SAME POSITION AS PIECE OCCUPIES IN ASSEMBLED MACHINE.
	WORK ALL VIEWS TOGETHER. DO NOT TRY TO FINISH ONE VIEW BEFORE BEGINNING ANOTHER.
DOTTED LINES	USE FEW DOTTED LINES ONLY WHEN ABSOLUTELY NECESSARY.
	USE CROSS SECTIONS FREELY IN PREFERENCE TO DOTTED LINES.
PENCIL WORK	MAKE PENCIL DRAWING SHARP AND DEFINITE, ABSOLUTELY COMPLETE, AND CHECK CAREFULLY BEFORE TRACING.
TR. CLOTH.	USE ROUGH SIDE OF TRACING CLOTH TO PREVENT CURLING.
CHARACTER OF LINES	LINES FOR SIMPLE LARGE SCALE DETAILS THUS:
	" " COMPLICATED SMALL " "
	" DOTTED "
	" CENTER OR AXIAL { SOLID / DASH AND DOT "
	" DIMENSION " $4\frac{1}{8}$"
	" CROSS SECTION $\frac{1}{16}$" TO $\frac{1}{8}$" APART
COLOR	USE BLACK INK FOR ALL LINES
FIGURES	MAKE FIGURES BROAD, BOLD AND ABSOLUTELY CLEAR.
	MAKE ALL FIGS. READ FROM LOWER OR RIGHT HAND SIDE OF SHEET.
DIMENSIONS	MAKE ALL DIMENSIONS IN INCHES UP TO AND INCLUDING 36 INCHES.
	ANY DIMENSIONS NEED OCCUR BUT ONCE ON SAME DRAWING.
ALLOWABLE ERROR	DIMENSIONS OF PARTS OF A MACHINE REQUIRING GREAT ACCURACY SHOULD BE INDICATED ON DRAWING WITH PLUS AND MINUS ERROR THUS: DIAMETER OF SHAFT 3.625" $^{+.000"}_{-.003"}$
NOTES	USE ENOUGH DIMENSIONS TO ENABLE THE PIECE TO BE MADE NO MORE—NO LESS! USE NOTES FREELY TO CLEAR UP DOUBTFUL POINTS.
THOUGHT	ALWAYS HAVE IN MIND THE WORKMEN WHO ARE TO USE THE DRAWING, THE PATTERN MAKER, BLACKSMITH AND MACHINIST.
	ALWAYS CONSIDER THE MACHINES AVAILABLE FOR THE WORK.



LONGITUDINAL AND TRANSVERSE SECTIONS OF MIETZ AND WEISS OIL ENGINE

Courtesy of August Mietz, New York City

MACHINE DRAWING

PART II

MECHANISM DRAWING

Study of Mechanisms. In Machine Drawing, Part I, working shop drawings have been analyzed in detail, systematic processes for making them have been outlined, and numerous illustrations given and thoroughly discussed. The student as yet, however, has not been shown how to originate the theoretical outlines of the surfaces controlling motion in machines; and it is the purpose of Part II to accomplish this.

The theoretical shape of the working surfaces of a machine can be studied and developed to best advantage without any consideration as to their strength or their ability to perform work or withstand service. Such study is a study of the mechanism of a machine, and must always precede the study of design to provide the proper strength.

A mechanism, therefore, is a combination of parts so formed and connected as to produce a desired motion, but not necessarily to perform any specific work.

A machine is a working mechanism, or a combination of mechanisms, suitably designed for the performance of specific work.

Mechanism drawing is really the first step in machine design; and all the familiar parts of machines, such as springs, screws, cams, pulleys and belts, gears, etc., are dependent for their existing practical form upon their theoretical layouts as mechanisms, involving exact mathematical principles. The student should pursue carefully the study of motion as applied to the development of the common machine parts, as this study is fundamental to the advanced work which follows it.

HELIX

Development of Helix. Since most coil springs and all screw threads depend upon a curve known as a helix, it will be necessary to know what a helix is, and how it can be drawn, before taking up the construction of springs and screws.

Suppose we take a cylindrical piece of wood, such as is shown in Fig. 51, and a rectangular piece of paper $ABFE$, with the side AB equal to the circumference of the cylinder, and the side AE equal to the length of the cylinder. If we lay off along AE any

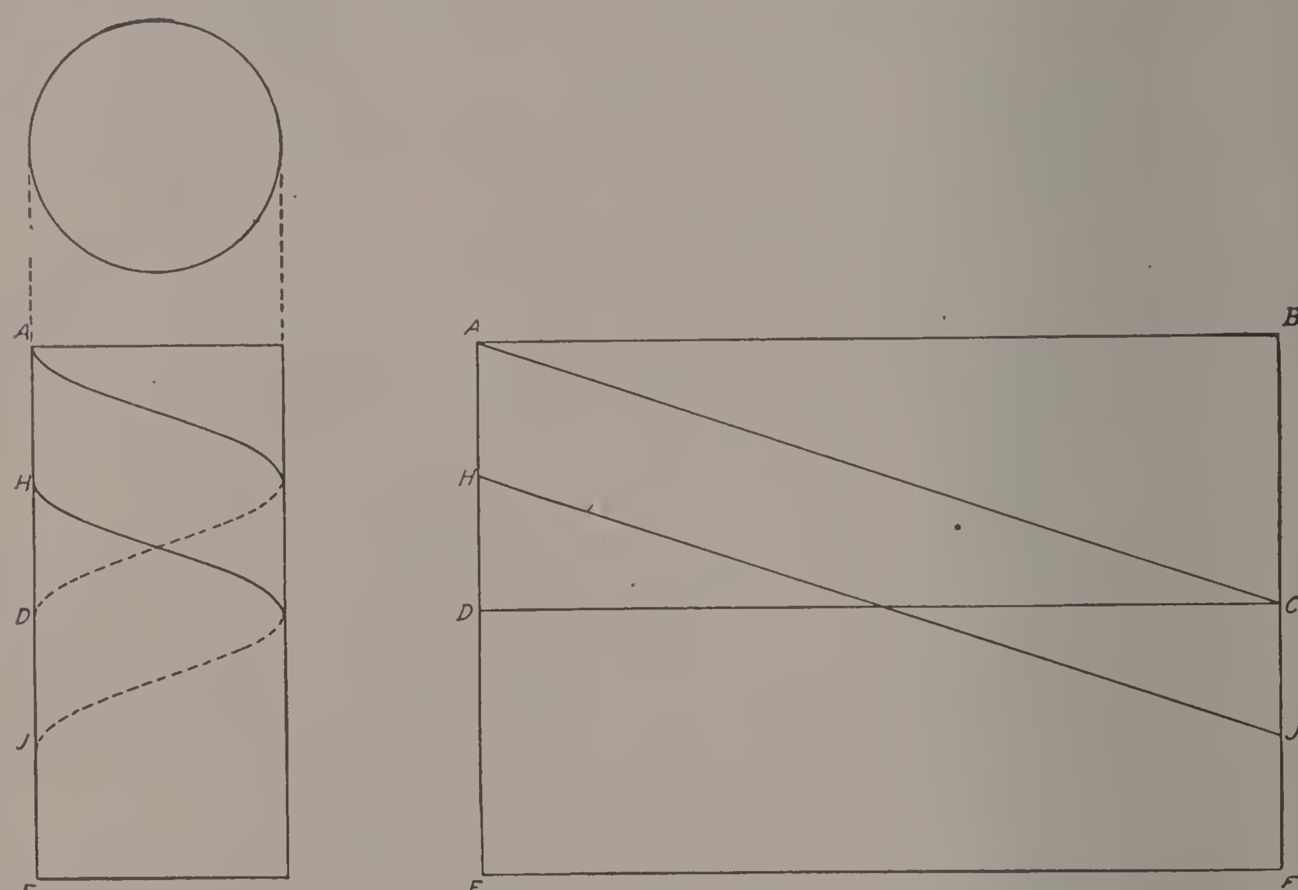


Fig. 51. Diagram of Simple Helix Construction

convenient distance AD, and draw the line DC parallel to AB, we have the rectangle $ABCD$. Now draw the diagonal AC of this rectangle and wrap the paper around the cylinder, keeping the side AE on an element of the cylinder; the paper will just cover the cylinder, the edge BF meeting the edge AE. The point C coincides with the point D, and is on the same element of the cylinder as A; therefore the line AC has made one complete turn around the cylinder, advancing the distance AD in this turn. The curve which the line AC now takes is called a helix, and the distance AD is called the pitch of the helix.

If on the piece of paper we also choose a point H, half way between A and D, and draw from this point a line HJ parallel to line AC, this line HJ will form another helix parallel to the helix formed by the line AC, when the paper is wrapped around the cylinder. The pitch of both helices is the same.

The helix is often incorrectly called a spiral, but there is a marked difference between the two. The spiral is a curve which lies in one plane and winds around a point, constantly receding from the point, according to some law. The mainspring and hair-spring of a watch are in the form of spirals.

Construction of Curve. To draw the projections of a helix we must know the diameter of the cylinder upon which the helix is formed, and the pitch of the helix. Fig. 52 shows the construction.

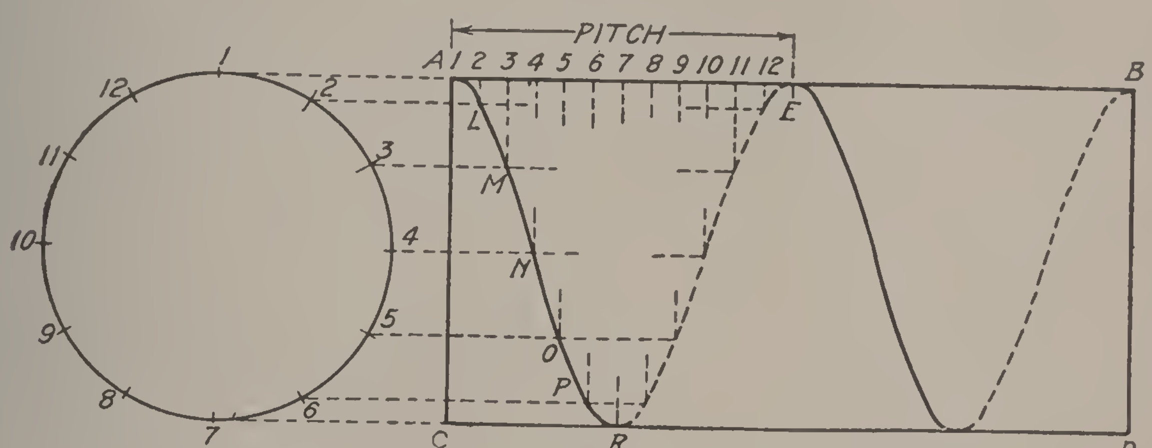


Fig. 52. Diagram Showing Construction of Right-Hand Helix Curve

Draw two projections of the cylinder $ABDC$; along any element, preferably one of the contour elements AB or CD, lay off the pitch AE. Divide the circumference of the circle, which is the end view of the cylinder, into any number of equal parts, and number the points of division *1*, *2*, *3*, etc. Divide the pitch AE into the same number of equal parts, and number these points of division in the same way that the points on the circle are numbered, calling A point *1*. From point *2* on the circle, draw a line parallel to AB; and from point *2* on AB, draw a perpendicular to AB. The point L, where the parallel line meets the perpendicular line, is one point on the projection of the helix. The points M, N, etc., are found in the same manner. A smooth curve starting from A, going through all the points and ending at E, will be the projection of one turn of the helix. The half from A to R is on the front, and is, therefore,

a full line, while the half from R to E is on the back and is a dotted line. It should be observed that the point R is on the perpendicular from 7, which is just half-way between A and E; that is, the distance

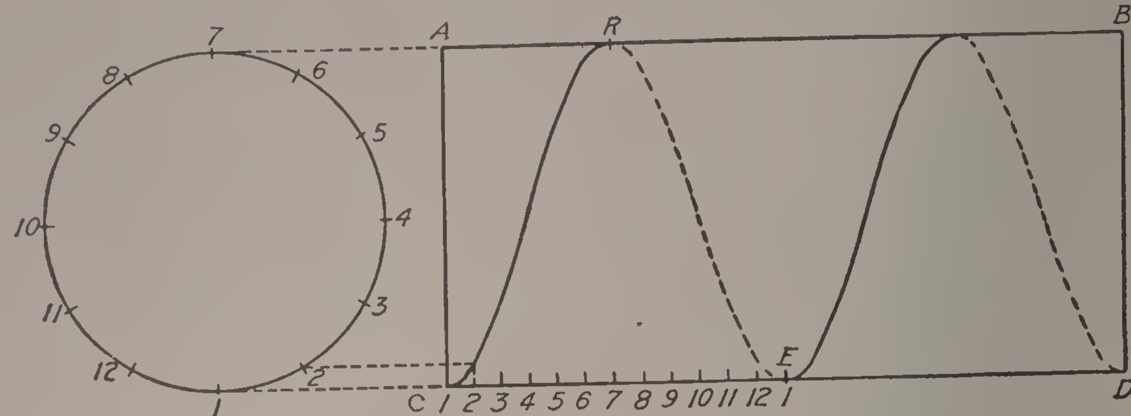


Fig. 53. Diagram of Left-Hand Helix Curve

CR is just one-half the pitch. The curve from E to B is the projection of the next turn of the helix and is exactly like the first one.

The helix shown in Fig. 52 is called a right-hand helix. If the curve starts at C and is drawn as in Fig. 53, we have a left-hand helix. Notice that the visible part (from C to R) slants in the same direction as the invisible part of the right-hand helix, which is shown dotted in Fig. 52.

Since the helix is a line drawn on the surface of a cylinder, the other projection of the helix must be the circumference of the circle, which is the end view of the cylinder. Fig. 54 shows a right-hand double helix, and Fig. 55 is a right-hand triple helix.

The construction of these curves should be studied carefully in order that springs and screw threads may be better understood.

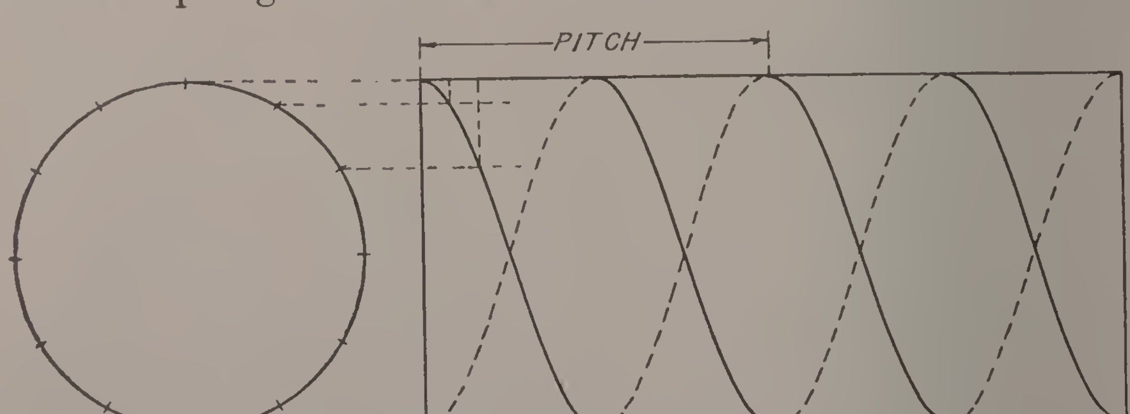


Fig. 54. Diagram of Right-Hand Double Helix

Helical Springs. *Accurate Representation of Springs.* If, instead of winding a line around a cylinder in the form of a helix, as shown in the preceding figures, we wind a piece of spring wire, we shall get a helical spring.

Fig. 56 is the drawing of a helical spring of round wire, the side view only being drawn, as this is all that is necessary to give all the dimensions. To draw the spring we must know the pitch, the

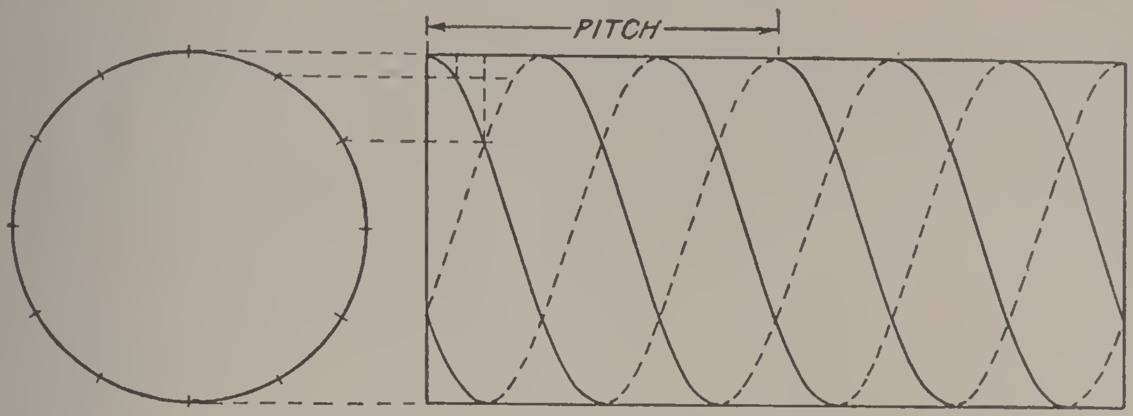


Fig. 55. Diagram of Right-Hand Triple Helix

diameter of the wire, and either one of the dimensions *A*, *B*, or *C*. If *A* is given, we subtract from *A* the diameter of the wire to find *B;* and if *C* is given, we add to *C* the diameter of the wire to get *B;* then, knowing *B* and the pitch, we can draw the helix (which is shown in dotted lines) exactly as the helix was drawn in Fig. 52. This is the helix formed by a line in the center of the wire. Now draw a series of circles with centers on this helix and of a diameter equal to the diameter of the wire. Smooth curves drawn tangent to these circles, as shown in the figure, will give the projection of the spring.

Fig. 57 shows a helical spring of square wire. The drawing of this is simply the drawing of four helices, starting from each of the corners of the square *ACML;* this square being the cross section of the wire of which the spring is made. All four of the helices

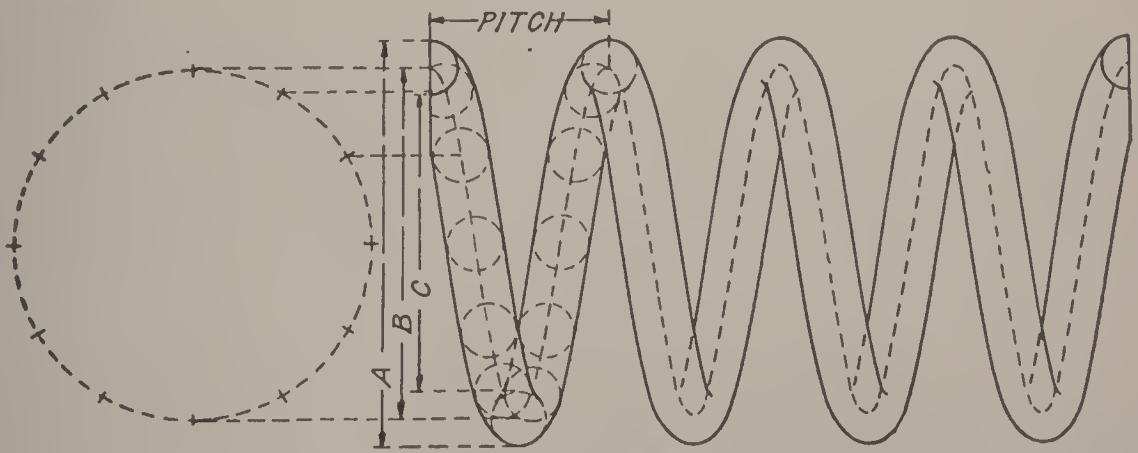


Fig. 56. Accurate Diagram for Helical Spring of Round Wire

have the same pitch, equal to *AB* for, since the square *BDPN* is the same as *ACML*, the distance *CD* is the same as *AB;* and since the points *L*, *M*, *N*, and *P* are vertically under *A*, *C*, *B*, and *D*,

respectively, the distance LN is equal to AB, and MP is equal to CD. The helix AFB has a diameter equal to that of the circle IE, and is drawn by dividing the circle IE and the pitch AB, as in Fig.

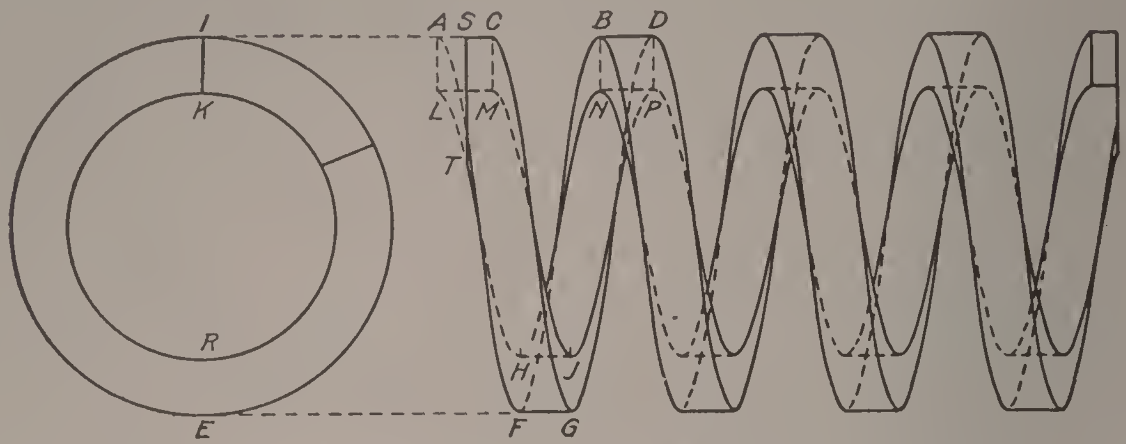


Fig. 57. Accurate Construction for Helical Spring of Square Wire

52; and the helix CGD, having the same diameter as AFB, is drawn by dividing circle IE and pitch CD. The helix LHN has a diameter equal to that of the circle KR, which is IE minus twice the thickness of the wire, and is drawn by dividing up the circle KR and the pitch LN; and the helix MJP, having the same diameter as LHN, is drawn by dividing circle KR and pitch MP. Since the two circles are drawn about the same center, the divisions on circle KR can be found by drawing radial lines from the points of division on circle IE. The vertical lines drawn from the divisions of the pitch AB can be used for the divisions of LN; and those drawn from divisions of CD can be used for MP.

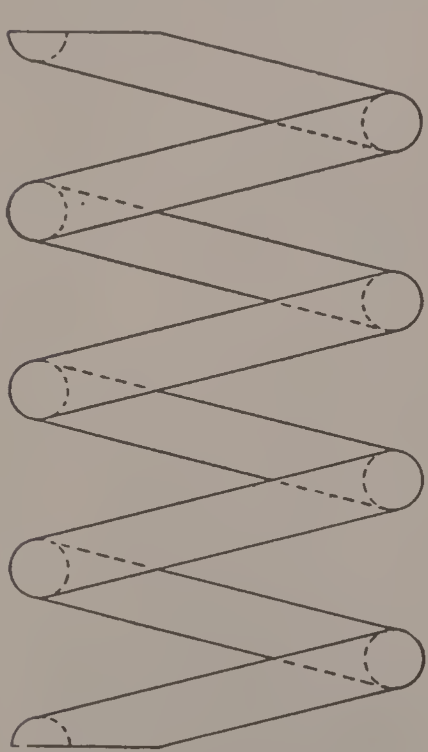


Fig. 58. Conventional Drawing for Spring of Round Wire

After the four parallel helices are drawn, it is necessary to study the drawing carefully, to decide what lines will be visible (full lines) and what invisible (dotted lines). Dotted lines should be used from H to J, N to P, etc., and full lines from F to G, B to D, etc. The line ST is the end of the spring, and consequently any part of a helix which goes outside of that line should not be left on the finished drawing. It is better, however, to draw in the whole of the square $ACML$, and to draw the helices starting from A to L, in order to draw those parts of the same helices

which lie to the right of ST. The parts to the left of ST are shown in the figure by light, dotted lines to indicate that they are construction lines, and not a part of the projection of the spring itself.

Conventional Representations of Springs. To draw springs by the method just explained involves considerable work and would consume a great deal of time if many were to be drawn; therefore, in working drawings, the draftsman commonly uses a conventional method. This conventional drawing is similar to the true projec-

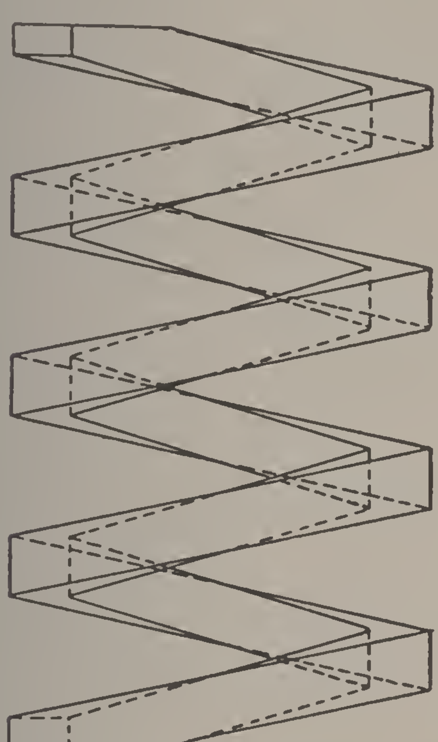


Fig. 59. Conventional Drawing for Square Wire Spring

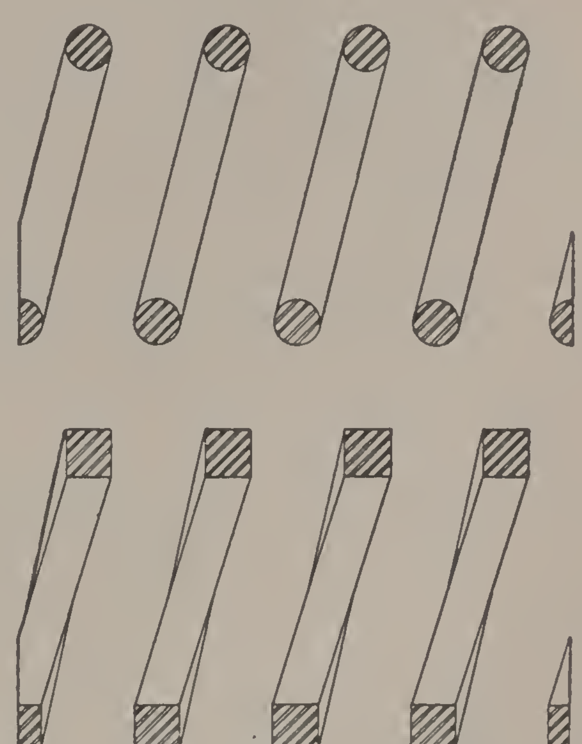


Fig. 60. Half-Sections of Round and Square Wire Springs

tion, except that straight lines are used in place of curved lines. Fig. 58 shows the conventional drawing of a spring of round wire; and Fig. 59, of a spring of square wire. Springs are often shown in half-section, as in Fig. 60, this method involving less work than the method of Figs. 58 and 59.

SCREW THREADS

Screw and Nut. If we cut a groove around a cylinder in the form of a helix, we shall have what is called a screw thread, the thread being formed by the material which is left between the successive turns of the helical groove. A cylinder having such a helical groove cut around it is called a screw; and a piece having a cylindrical hole

in it, with a helical groove cut around the hole, is called a nut. The most common uses of the screw are to fasten pieces together, to hold

Fig. 61. Simple Drawing for Left and Right-Handed V Screw Threads

them at a given distance apart, and to cause one piece to move with relation to another piece.

V Thread. The form of screw thread with which we are most familiar is what is known as the V thread, shown in its simplest form in Fig. 61. Fig. 62 shows the method of drawing the true projections of this thread. The dimensions which must be known in order to

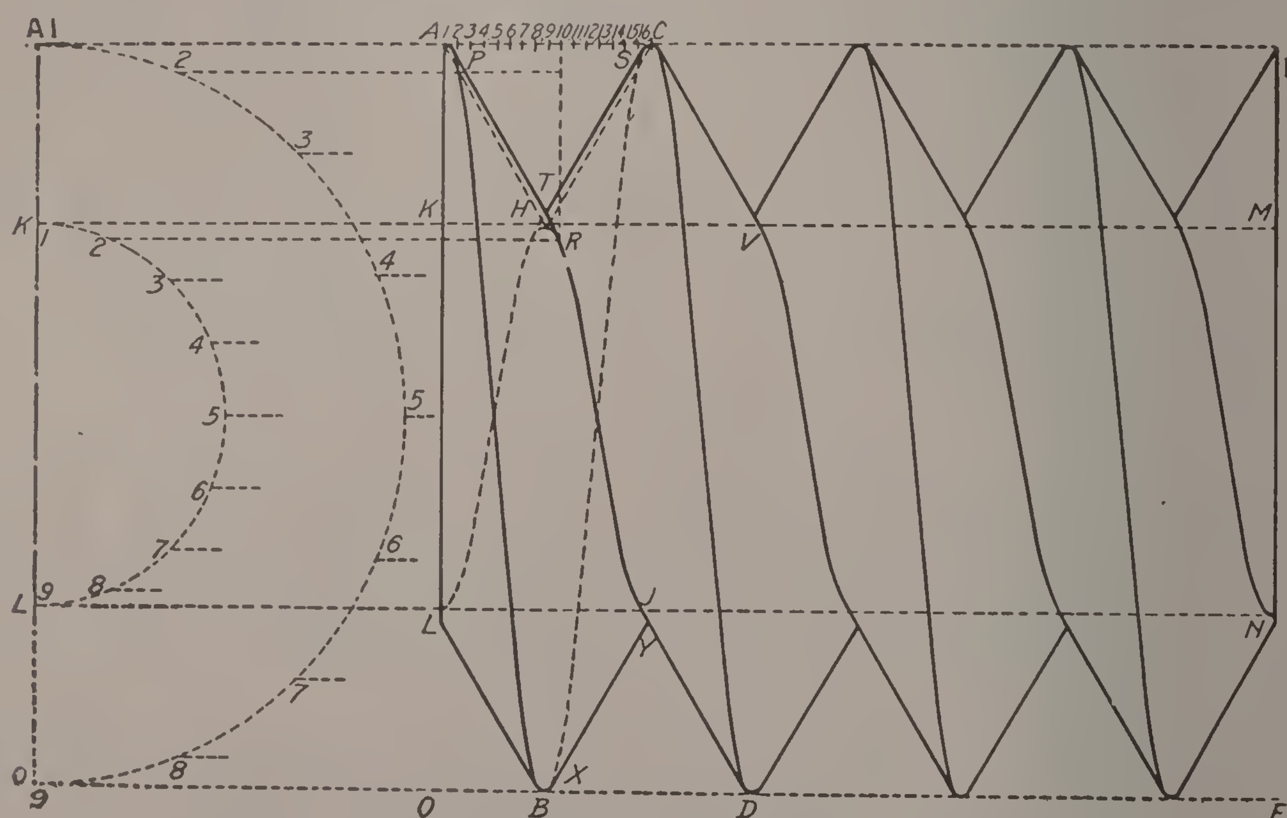


Fig. 62. Accurate Projections of the Right-Hand V Screw Thread

make the drawing are the outside diameter AO, the pitch AC, and the depth of the thread AK. First draw the two projections of a cylinder of a diameter equal to the outside diameter of the screw. Half of the end view is sufficient. On the line AE of this cylinder

lay off AC equal to the pitch; starting at A, draw the helix $ABCD$, as described for Fig. 52. Inside of the cylinder AO, draw a smaller

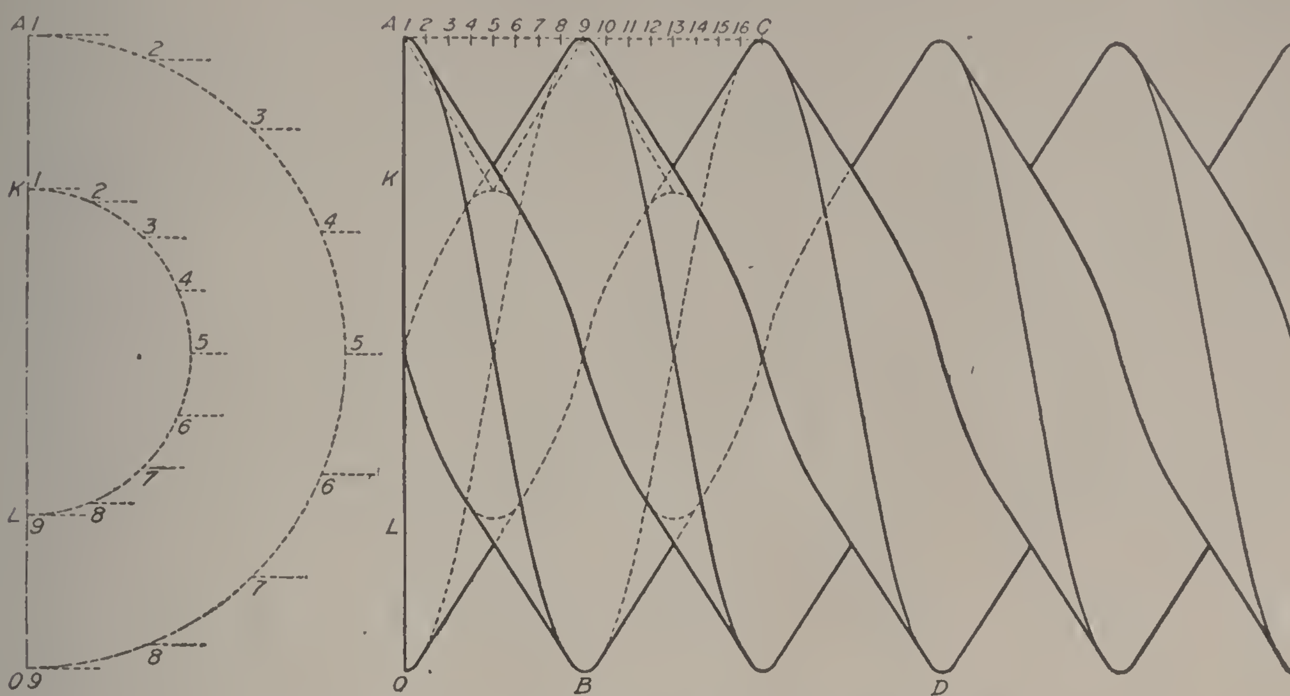


Fig. 63. Accurate Construction for Double V Thread

cylinder KL, the diameter of which is equal to the diameter AO minus twice the depth of the thread. Now, on this smaller cylinder, starting at point H, perpendicularly under a point on the line AC which is half way from A to C, draw the helix LHJ with the same pitch as was used for the helix ABC. Draw the lines PR, XY, ST,

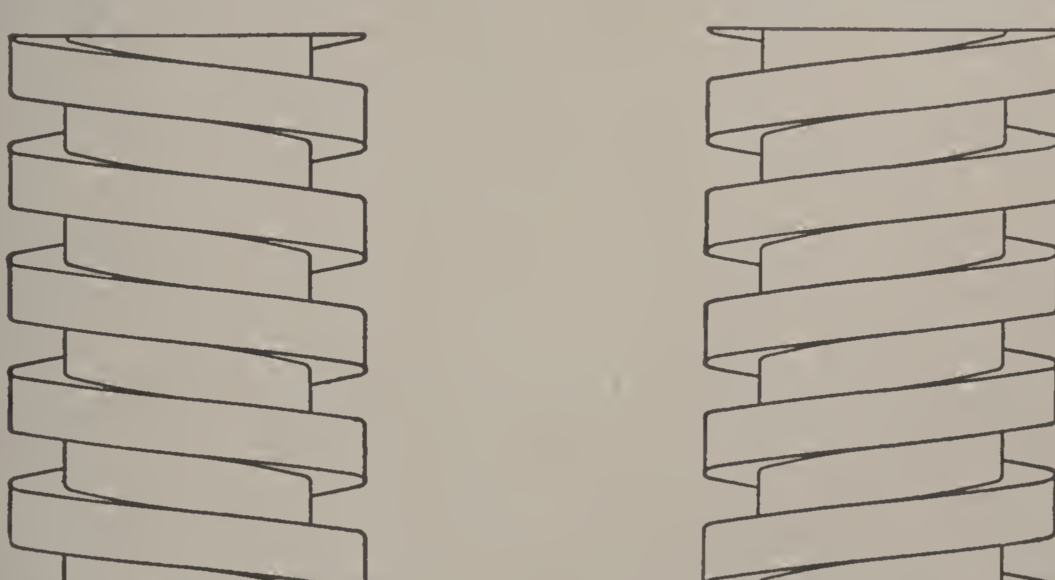


Fig. 64. Simple Drawing of Left- and Right-Handed Square Screw Threads

etc., tangent to the two helices and the projection of the thread is completed. It is necessary to draw the invisible parts of the two helices in order to draw the lines ST, XY, etc.; but they need not be left on the finished drawing. In Fig. 62 they are shown dotted for one turn of the screw, in order to indicate the construction.

Fig. 63 shows the method of drawing a double V thread. The process is exactly the same as for drawing a single thread. Start at point *A*, and draw the single thread *ABCD* exactly as in Fig. 62; then start at point *9*, half way between *A* and *C*, and draw another single thread of the same pitch as the first one. Some thought may be necessary to decide when the lines of one thread become hidden behind the other thread.

Square Thread. Another very common form of screw thread is that shown in Fig. 64, and known as the square thread. The method of drawing this thread is similar to that for the V thread, with the exception of a few minor points. The construction is shown

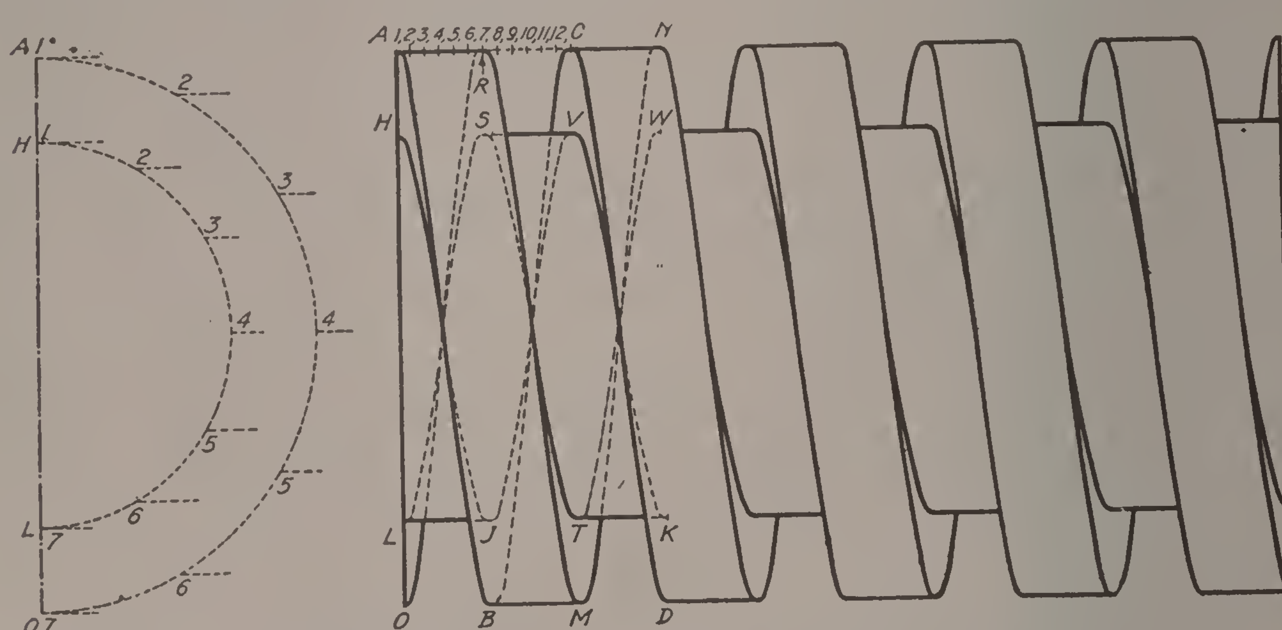


Fig. 65. Accurate Projections for Right-Handed Square Screw Threads

in Fig. 65. The dimensions which must be known are the outside diameter *AO*, the pitch *AC*, the depth *AH*, and either the width of the thread *AR*, or the width of the groove *RC*. In the figure, the width of the thread *AR* is taken equal to one-half of the pitch; that is, *AR* and *RC* are equal. Beginning at *A*, draw the helix *ABC;* and beginning at *R*, draw the helix *RMN*, *RN* of course being equal to *AC*. Since the part between *A* and *R* is metal, forming the thread, there will be a line from *A* to *R* and from *B* to *M*, etc. Now, starting at point *H*, vertically under *A*, and at a distance from *A* equal to the depth of the thread, draw the helix *HJV;* and from *S*, vertically under *R*, draw helix *STW*. Draw the lines *SV*, *TK*, etc. Here, as in the case of the V thread, the invisible lines must be drawn when making the drawing, but need not be inked.

Fig. 66 shows the construction of a double square thread. An explanation is not necessary, since the difference between this and the single square thread is practically the same as between the single and double V thread.

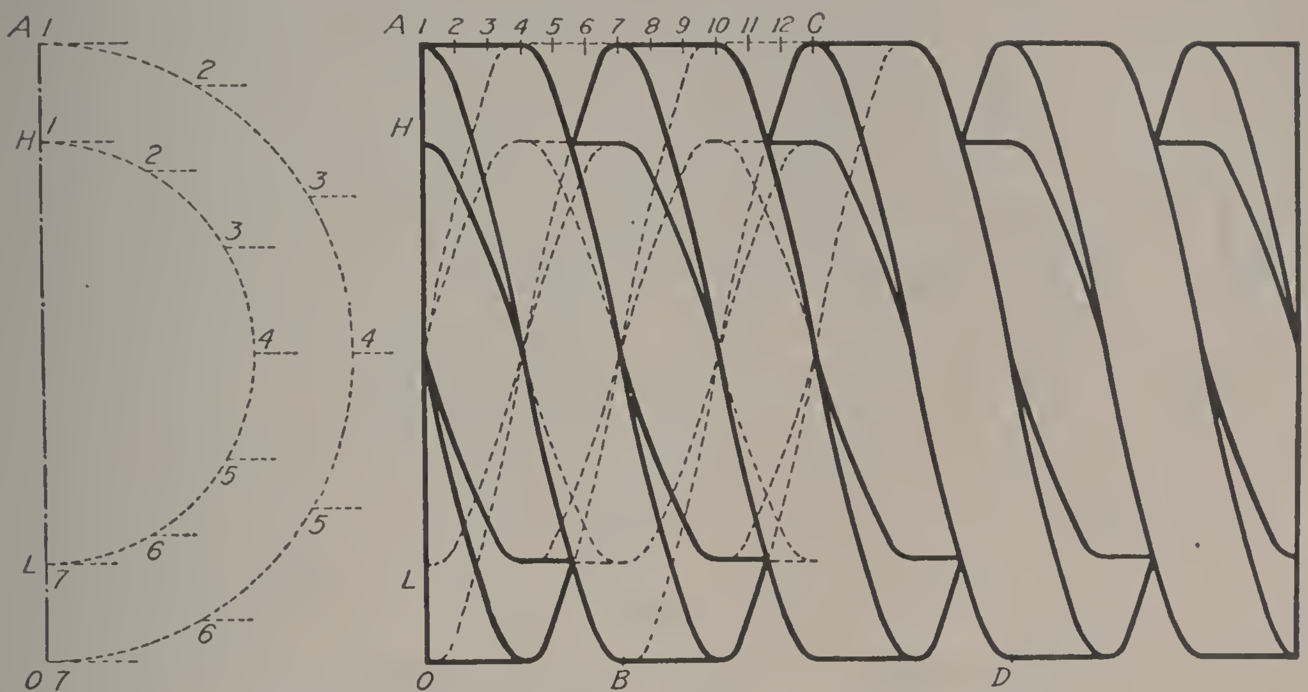


Fig. 66. Accurate Construction for Double Square Thread

Typical Forms of V and Square Threads. The V and square threads are the two fundamental forms of thread in use, and all other forms are modifications of one or the other of these two. Figs. 67 to 70 show some of the more common modifications.

Figs. 67 and 68 show the two forms of the V thread which are commonly used in practice.

U. S. Standard Thread. In Fig. 67 we have what is known as

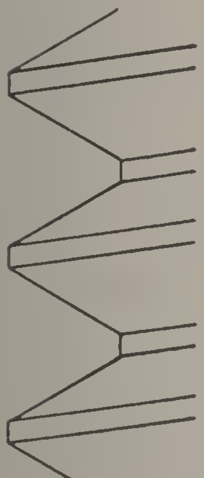


Fig. 67. U. S. Standard Thread

Fig. 68. Whitworth Standard Thread

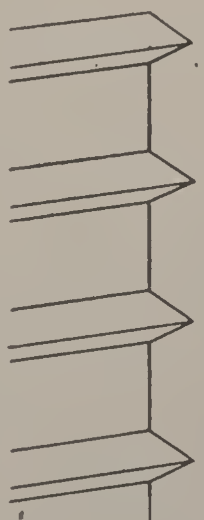


Fig. 69. Lag Screw V Thread

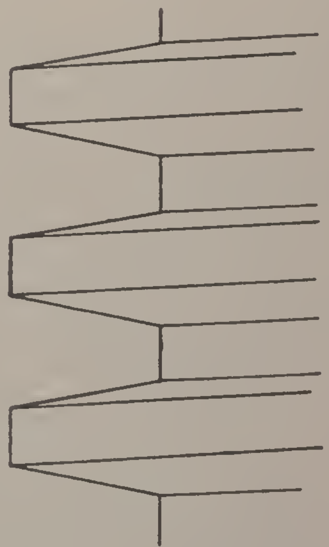


Fig. 70. Variation of Square Thread

the Sellers or United States standard thread, an enlarged drawing of which is shown in Fig. 71. Referring to this figure, we see that

the angle between the two sides of the thread is 60°, so that if the thread came to a point at the top and bottom, as indicated by the dotted lines, the depth of the thread D would be about $\frac{87}{100}$ of the pitch P. The sharp corners, however, are a disadvantage, since on the outside they are likely to be bruised and to give trouble in putting on the nut, and at the bottom of the groove they tend to weaken the bolt or screw. In order to avoid these sharp corners, the threads are flattened in the United States standard thread, as shown in Fig. 71, the amount of this flattening being such that the distance C is $\frac{1}{8}$ of the pitch, or—what amounts to the same thing—the distance A is $\frac{1}{8}$ of D. This gives a thread whose depth E is $\frac{65}{100}$ of the pitch.

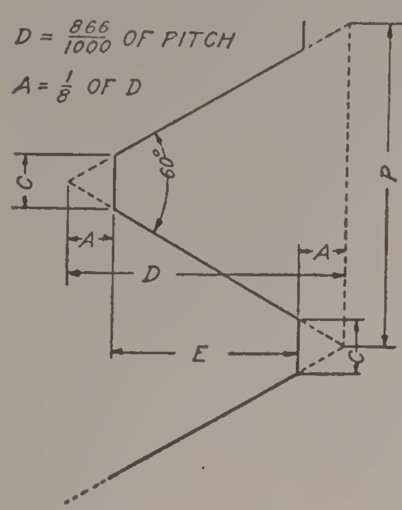


Fig. 71. Enlarged U. S. Standard Thread

Whitworth Standard Thread. Fig. 68 illustrates what is known as the Whitworth standard thread, shown enlarged in Fig. 72. Here the angle between the sides of the thread is 55°, so that if the threads came to sharp corners, as shown by the dotted lines, the depth D would be $\frac{96}{100}$ of the pitch. The top and bottom of the thread, instead of being flattened, are rounded off so that the distance A is $\frac{1}{6}$ of D, or the depth E is $\frac{64}{100}$ of the pitch.

Lag Screw V Thread. Fig. 69 shows the V thread as used on lag screws and other wood screws. Here the groove is much larger than the thread, because the wood into which it is to screw is weaker than the iron of which the screw is made.

Variation of Square Thread. Fig. 70 shows a slightly modified form of square thread, the only difference between this and the square thread previously described being that the sides of the groove taper slightly.

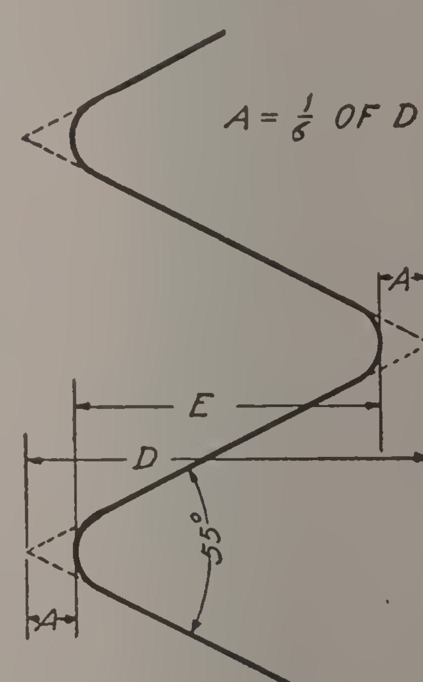


Fig. 72. Enlarged Whitworth Standard Thread

Conventional Representations of Screw Threads. The student should understand the drawing of the threads, as previously explained; and every draftsman should be able to draw the true projection of a thread if he should have occasion to do so. It is evident,

however, that the process is complicated, and on a screw of small diameter and pitch it would be difficult to follow out the construction. To avoid this labor the construction shown in Figs. 73, 74, and 75 may be adopted, straight lines being substituted for the projections of the helix. Fig. 73 shows the conventional representation of the plain, single, right-hand V thread, the true projection of which was shown in Fig. 62. To make the conventional drawing (Fig. 73), draw the parallel lines AB and CD at a distance apart equal to the outside diameter of the screw, and draw the line AC perpendicular to these two lines. Along A, lay off the distances AE, EF, etc., each equal to the pitch. Along CD, lay off CH equal to $\frac{1}{2}$ the pitch; and from H, lay off HI, IJ, etc., equal to the pitch. Draw lines from A to H, E to I, etc. Now, if the depth of the thread AS is known, draw the lines ST and UV; and beginning at L, perpendicularly under a point halfway between A and E, lay off LM, MN, etc., equal to the pitch. In like manner find the points O, P, R, etc., and draw the lines LO, MP, etc.; also AL, LE, HV, HO, etc. The dotted lines should be left out in the finished drawing, but are put in the figure to show the construction.

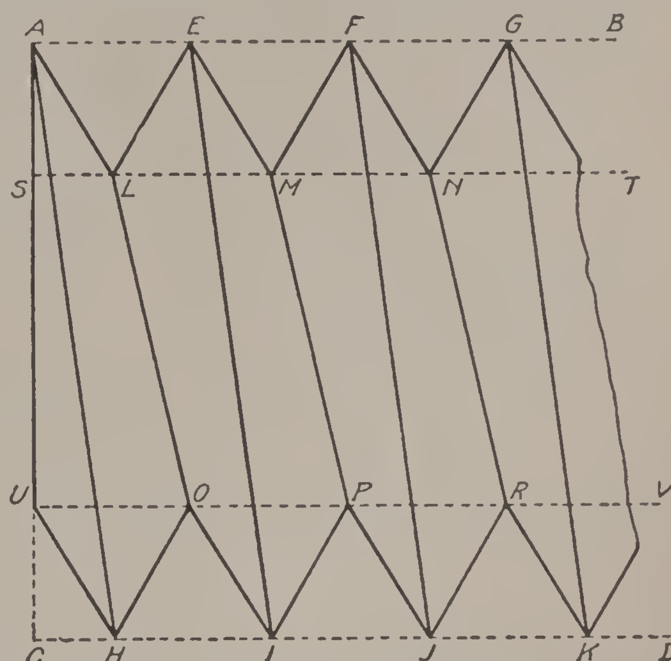


Fig. 73. Conventional Drawing for Right-Hand V Thread

If, instead of knowing the depth AS, we know the angle between AL and LE, the depth can be found by drawing from A and E the two lines AL and EL in such a way that they make the required angle with each other. To do this, the lines AL and EL should each make an angle with the line AB equal to 90° minus $\frac{1}{2}$ the angle between AL and LE.

Fig. 74 shows the corresponding construction for the United States standard thread. Draw the lines AB, CD, and AC as in Fig. 73, and find the points E, F, G, H, I, J, K, etc., in the same way as in that case. Now draw the lines ST and UV so that AS and CU shall equal $\frac{65}{100}$ of the pitch AE. On the line AB, lay off from

A a distance *A1* equal to $\frac{1}{16}$ of the pitch; and on each side of *E*, *F*, *G*, *H*, etc., lay off *E2*, *E3*, etc., each equal to $\frac{1}{16}$ of the pitch. From the points thus found, draw lines *1—4*, *2—5*, etc., making an angle of 60° with *AB*. The rest of the drawing is completed as shown by drawing in full lines those parts of the lines *AB*, *CD*, *ST*, and *UV* intercepted between *1—4* and *2—5*, etc.

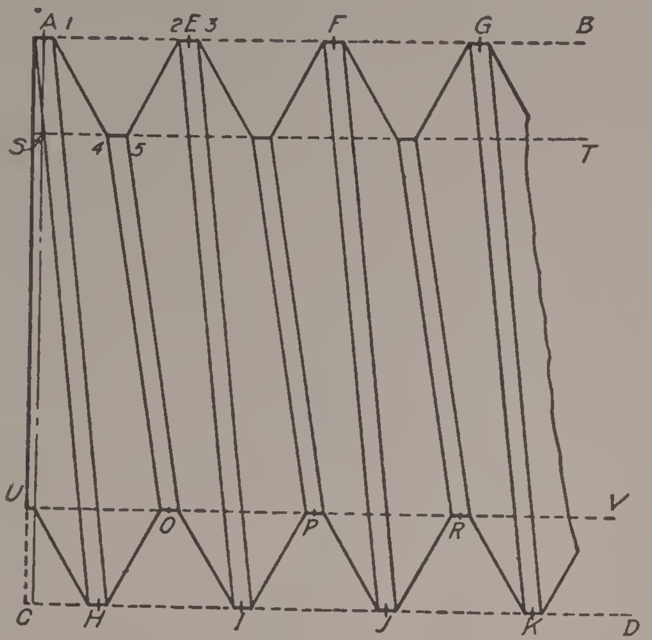


Fig. 74. Conventional Drawing for U. S. Standard Thread

Fig. 75 shows the conventional representation of a square thread, and is drawn in exactly the same way as the true projection shown in Fig. 65, except that straight lines are used instead of curves, and certain other minor lines omitted.

Square threads are seldom conventionalized more than as shown in Fig. 75, and V threads of coarse pitch and large diameter are usually drawn as in Fig. 73, whether sharp or U. S. standard. But for ordinary screws of small diameter and fine pitch, as are most frequently used, such a method involves too much labor, and the use of alternate long and short dashes across the body of the screw, as shown in Machine Drawing, Part I, Fig. 14, is universally employed.

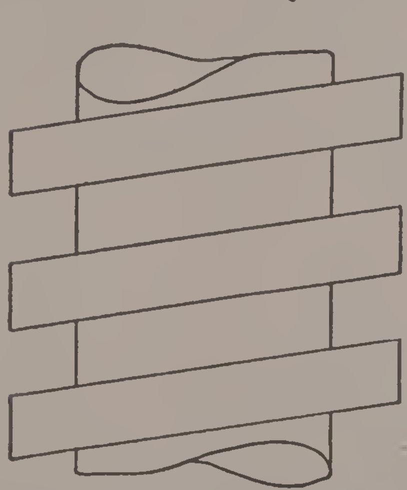


Fig. 75. Conventional Drawing for Square Thread

CAMS

Mechanical Action. A cam is an applied form of the ordinary wedge. The simple wedge is used to split apart the piece into which it enters, or to pry up heavy weights. It does not automatically repeat its work. The work of the wedge is finished when it is once driven home; and its function is not to produce motion, but to give mechanical advantage to the blows which drive it.

If we take a simple wedge and fasten it to some piece—say, a disk centered on a shaft, which is capable of continuous or periodic

rotation, and allow the face of the wedge to rub against another guided piece, called the *follower,* we have a cam. In Fig. 76 is shown a double wedge in which either sloping side produces against the follower the action just referred to. When we rotate the cam, it "wedges" the follower along a fixed path. When the follower reaches the top of the wedge, it may drop back to its original position, drawn by gravity or by the force of a spring, or it may be eased back by another wedge in the reverse position of the other, as shown in Fig. 76. This cycle will be repeated as long as we choose to rotate the cam. The cam, therefore, is essentially a repeating wedge, and its function is primarily one of motion rather than of great force. The wedge principle, however, enables very powerful cams to be made in cases where but little motion is desired. The motion of the cam is usually a rotation, but it may be an oscillation, or a straight-line reciprocating motion.

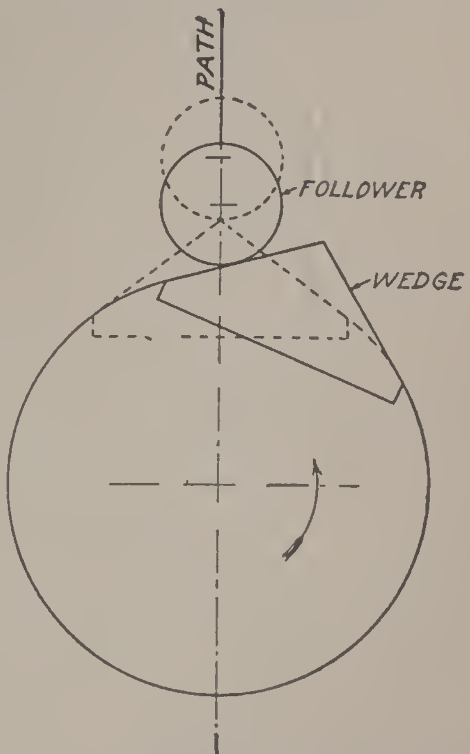


Fig. 76. Simple Diagram of a Cam

Factors in Design and Layout. In designing a cam, it is not only essential that the proper layout be made to produce, theoretically, the required motion of the follower, but that the wedge action be such that the cam will drive easily. Referring again to the wedge as a machine, a thin wedge, for example, may be forced under a heavy weight with a sharp blow, whereas a thick broad wedge cannot be made to lift the weight. For precisely the same reasons, cams designed with thin wedges will drive their followers with ease, while cams may be designed so steep in their wedge action that they drive with difficulty, and may even lock the follower in its path, on account of excessive side pressure. This is a very important element in a design, and the analysis will be brought out more clearly in the discussions of the line of pressure.

The actual laying out of a cam is simple in principle, although somewhat tedious, especially in complicated cams. Several positions of the follower in its path are chosen, the follower drawn in those positions, and then the face of the cam is drawn tangent

thereto. In order to do this, the several positions of the follower in its path may be laid down on the drawing paper as shown in Fig. 77. This fixes the limit through which the cam must move the follower. Now develop the cam itself on a separate piece of transparent paper or tracing cloth, Fig. 78, and place this over the follower layout with the centers of the two drawings coinciding, and a pin through this center of rotation of the cam. As the cam is rotated about this axis so as to correspond to the various positions of the follower shown on the drawing underneath, the follower can be traced in on the upper drawing in each position.

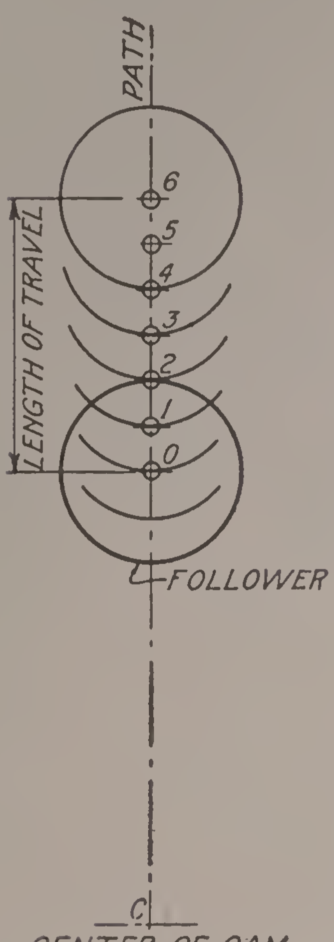


Fig. 77. Layout for Positions of Cam Follower

When the movement of the cam is complete, we have on the cloth a series of drawings of the follower; and, if we draw a tangent line to these, the line of the cam will be produced. This method, however, from the drawing-board standpoint, is clumsy and inaccurate, because of the wearing of the pinhole and the error of transferring the shape of the follower to the tracing cloth. It is readily seen by reference to Figs. 77 and 78, that the same result will be attained in a much easier and more accurate manner if we artificially rotate the follower about the cam on the drawing-board by means of a pair of compasses, laying off equal angles to complete one revolution of the cam and showing the follower in position at each step. This is shown in Fig. 81, and is the method usually followed in cam design. This does not mean that the tracing-cloth method should be discarded, for it is useful in studying complicated cam movements; and also in testing the cam development when it is completed, to make sure that no error has been made.

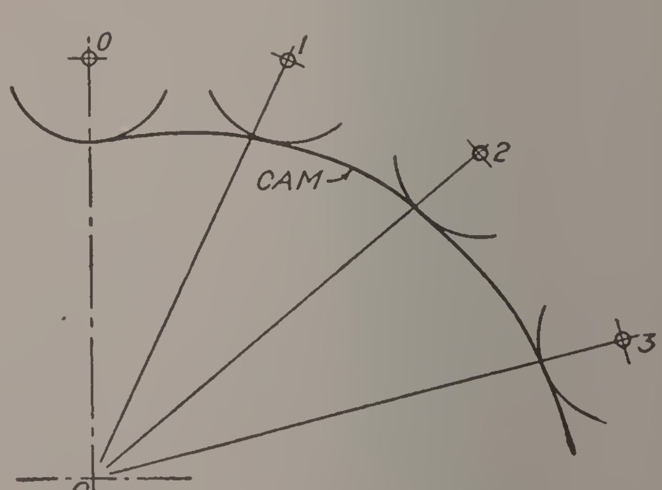


Fig. 78. Layout for Cam

PRACTICAL EXAMPLES IN LAYING OUT CAMS

Statement of Problems. From the principles just stated, the uniform course of procedure in laying out a cam is as follows:

1. Draw the follower in several positions in its path.
2. Draw cam radii corresponding to these positions.
3. Rotate the follower about the cam.
4. Draw tangent line.
5. Test the cam.
6. Draw the line of pressure for each position.

Plate Cams with Uniform Motion

In Figs. 79 to 86 inclusive, it is required to move the follower F with uniform motion from position 0 to 6, while the cam rotates through 150°; it is then to remain at rest during a cam movement of 30°; then to return to its original position, moving uniformly from position 6 to 0, while the cam turns through the remainder of the circle, or 180°. This is briefly expressed as follows: Uniform rise, 150°; rest, 30°; uniform fall, 180°.

Example 1. Pointed Follower with Path Intersecting Cam Center. 1. *Follower Positions.* The length of travel 06, Fig. 79, is supposed to be known, being fixed by some requirement of the machine to which the cam is to be applied. This distance, for a uniform motion, should be divided into any convenient number of equal parts; the more divisions, the more accurately can the cam be drawn. In this case six spaces are chosen.

2. *Cam Radii.* The diameter of base circle D is arbitrary; and its center having been chosen, draw the original radius CO; then the radii CX and CB, limiting the arcs of rise, rest, and fall, respectively, should be drawn. As the follower must rise $\frac{1}{6}$ of its travel while the cam rotates $\frac{1}{6}$ of its arc, there must be as many equal divisions of the cam arc as there are of the follower travel. Hence the arc of rise OX is divided into six equal parts and the radii are drawn. Similarly, the arc of fall OB is divided into six equal parts and the radii produced.

3. *Follower Rotation.* The rotation of the follower about the cam is accomplished by setting the point of the compasses at C, and, with radius $C1$, striking an arc intercepting the radius corresponding to position of the follower at R_1. Similarly, points R_2, R_3, R_4, R_5,

and R_6 are found. As the follower rests from X to B, the arc of intersection for R_6 is continued to F_6. For the period of fall, arcs are swung from the same points of follower travel as before, making the intersections F_5, F_4, F_3, F_2, F_1.

4. *Tangent Line.* A smooth curve is now drawn through the points of intersection, thus forming the outline of the cam. For other forms of follower than a sharp point, this line would be strictly

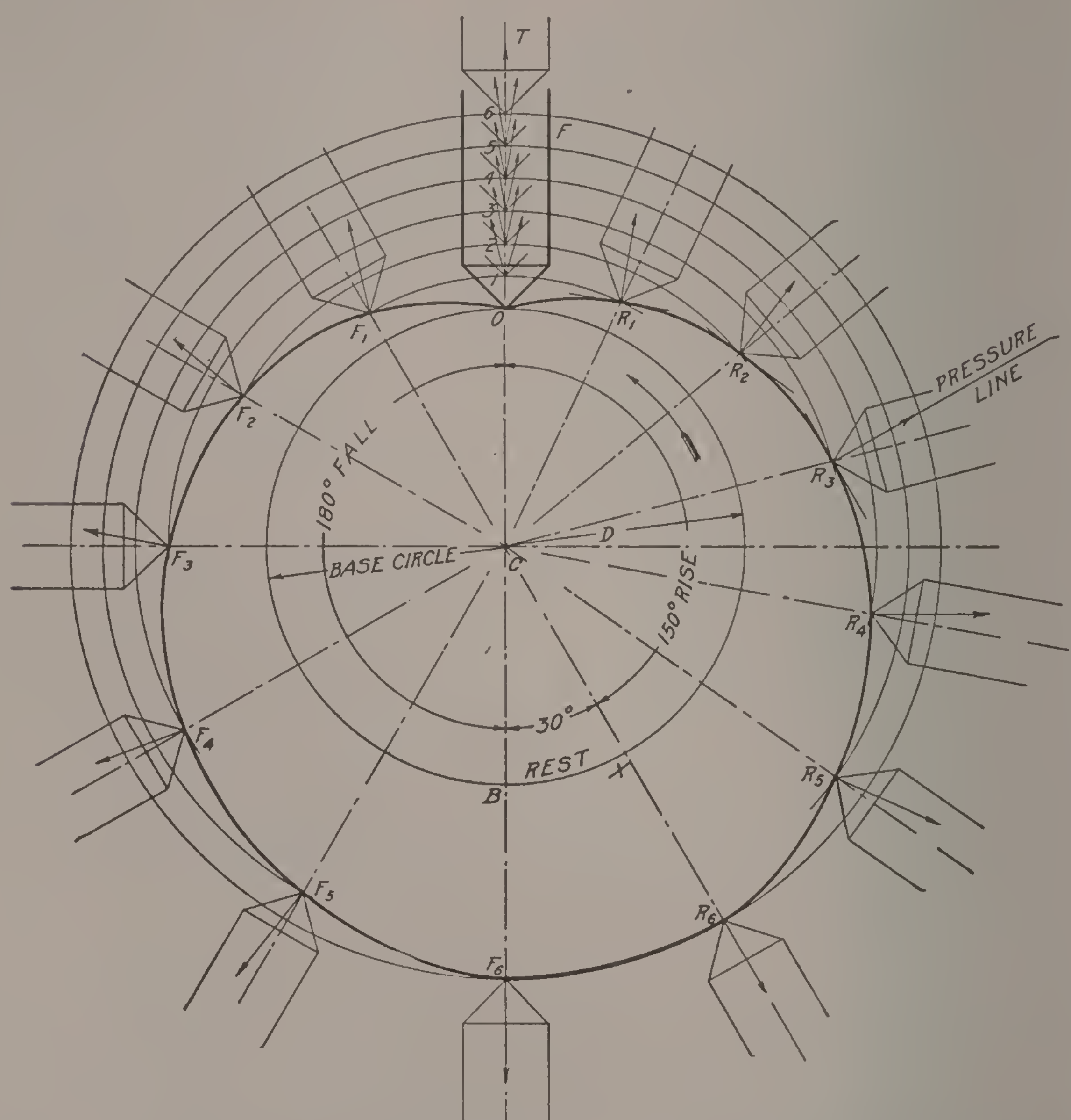


Fig. 79. Diagram for Cam with Pointed Follower Whose Path Intersects Cam Center

a tangent line to the face of the follower. A pointed follower, as shown in the figure, is not a very practical form, as the point is subjected to severe wear. It is chosen for the present illustration, to afford the simplest possible cam development.

5. *Testing.* The cam may be tested by laying over it a piece of tracing cloth, and tracing roughly the outline of the cam, also marking the radii and the center of rotation. A pin is now placed at the center of rotation of the cam, and the tracing cloth swung

until the several radii CR_1, CR_2, CR_3, etc., fall into the line of travel CT. If the cam is correctly developed, it will just touch the several positions of the follower in its path when the proper radius is coincident with the line of travel CT. It is very easy to make a mistake in laying out cams, especially the more complicated ones; and this rough method of proving the work should always be applied.

6. *Pressure Line.* The face of the follower in this case is a point, and the pressure line, being the common normal between the cam and follower at point of contact, is always theoretically normal to the cam at that point.

During motion, however, the force of friction between the cam and follower would modify somewhat the direction of the pressure line, turning it so as to produce a side thrust against the follower, causing consequent chattering and possible binding in its guides. This can be minimized by ample lubrication and hardened faces; but for cams which have any considerable load to work against, a follower carrying a roll against the cam is a necessity.

The line work in cam design should be fine and accurate. A hard pencil, kept well sharpened, is necessary, and special care must be taken to get definite intersections. In order to keep the center of the cam in as good condition as possible, it is well not to continue the radii to the center, but to stop when a short distance from the center, as shown. When penciling and inking in, use a fine, continuous line, not dotted; the continuous line is more quickly made and is apt to be more accurate than the dotted line. Moreover, the cam is strictly layout work, not finished in detail, and the subsequent detail drawing of the cam should not be confused with the layout of the cam outline.

Example 2. Pointed Follower with Path Not Intersecting Cam Center. 1. *Follower Positions.* The follower positions, Fig. 80, are chosen and drawn precisely as in Fig. 79; in this case, however, the path of the follower does not intersect the center of the cam, but, if produced, would pass at some distance to one side of it. This changes materially the development of the cam, as will subsequently be noted.

2. *Cam Radii.* The diameter of base circle and center of cam being chosen as before, draw the original radius CO. This original radius is the one to which all subsequent radii are related. Treating

this radius the same as the original radius CO in Fig. 79, the radius CX is drawn, making the arc of rise 150° as before. The radius CB is then drawn, giving the 30° arc of rest, and leaving the arc of fall between CB and CO 180° as before. Since the cam is to have uniform motion, the subdivisions of the arcs are equal, and are made in exactly the same manner as in Fig. 79.

3. *Follower Rotation.* The follower is now rotated about the cam by the compasses, in similar manner to that in Fig. 79, pro-

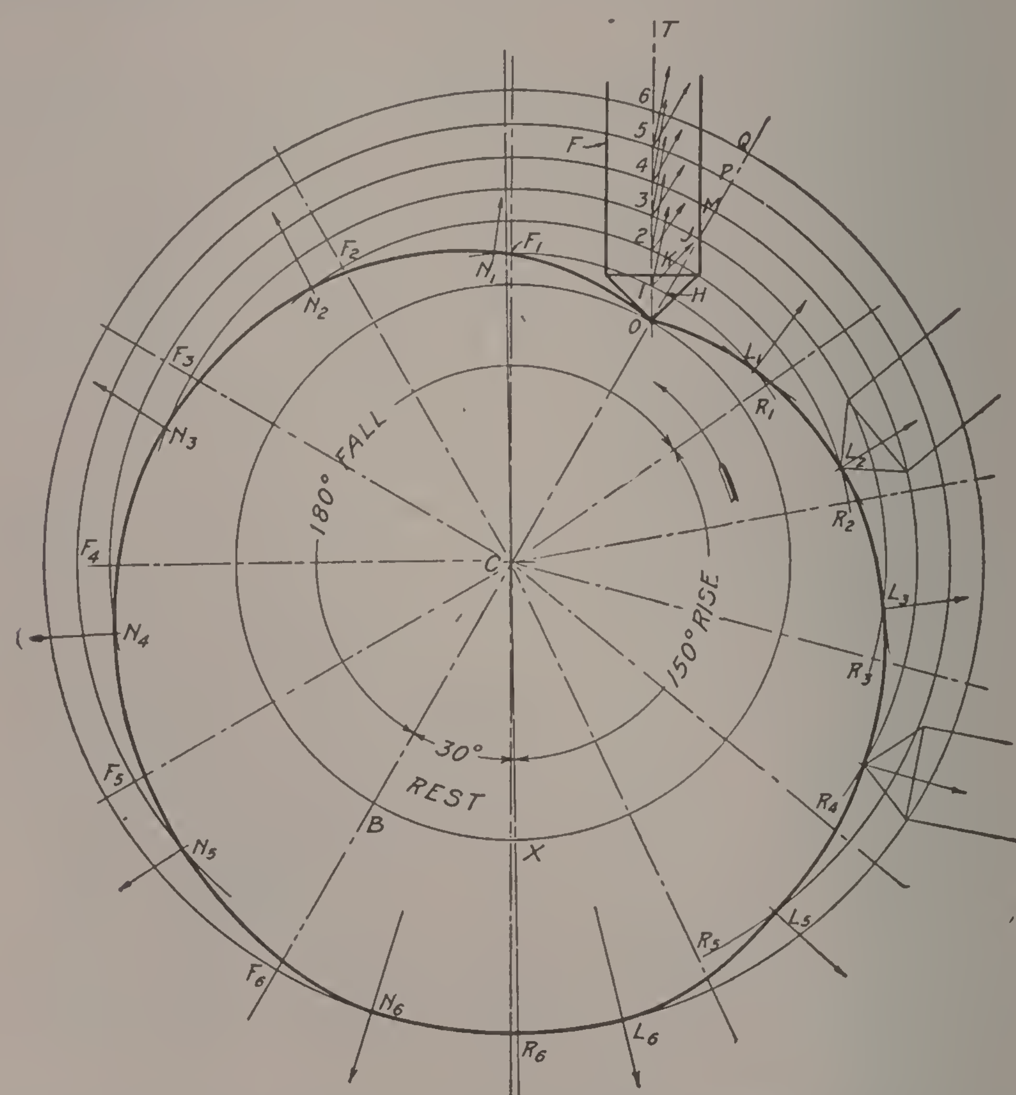


Fig. 80. Diagram of Cam with Pointed Follower Off Center

ducing the intersections R_1, R_2, R_3, R_4, etc. Now, however, the introduction of a new step should be noted. The original radius CO, not being coincident with the path of the follower OT, the intersections R_1, R_2, R_3, etc., do not represent the actual positions of the point of the follower when rotated. During the arc of rise, the follower is gaining on the radius, and the increasing distances R_1L_1, R_2L_2, R_3L_3, etc., must be set off ahead of the radii, equal to the distances $H1$, $K2$, $J3$, etc. In similar fashion, during the arc of

fall, the decreasing distances F_6N_6, F_5N_5, F_4N_4, F_3N_3, must be set off ahead of the radii, equal to $Q6$, $P5$, $M4$, $J3$, etc.

4. *Tangent Line.* A smooth curve is now drawn, not through the original points of intersection with the cam radii, as in Fig. 79, but through the points set off as above from these intersections. In other words, the cam curve is drawn through points L_1, L_2, L_3, L_4, etc., and N_6, N_5, N_4, N_3, etc.

5. *Testing.* A piece of tracing cloth should be laid over the cam, the outline traced upon it, the radii marked, and then the tracing cloth rotated about the pin point, as in Fig. 79, to see if the cam in its successive positions just touches the follower in each of its positions.

6. *Pressure Line.* The pressure line at each position of the follower is, as in Fig. 79, normal at the point of contact.

Example 3. Roll Follower with Path Intersecting Cam Center.

1. *Follower Positions.* In Fig. 81, the case is identical with that of Fig. 79, except that the shape of the follower has been changed to the more practical form of a roll, which can turn about a pin, thus relieving the crowding, grinding action characteristic of the pointed follower hitherto discussed. The path of follower roll F is divided as before into six equal parts.

2. *Cam Radii.* The original radius CO, the radius CX, limiting the arc of rise, the radius CB, limiting the arcs of rest and fall, are all drawn precisely as before, and the subdivisions of the arcs are in nowise changed from the preceding cases.

3. *Follower Rotation.* The follower is now rotated about the cam, giving the intersections R_1, R_2, R_3, R_4, R_5, and R_6 for the period of rise; the corresponding intersections for the period of fall are F_6, F_5, F_4, F_3, F_2, and F_1. With each of these intersections as a center, and a radius equal to the radius of the follower roll, an arc is struck, which represents the follower in its rotated position.

4. *Tangent Line.* A common tangent line is now drawn to the several positions of the rotated follower, giving the outline of the cam as a smooth curve. In order to give the follower its full period of rest from R_6 to F_6, the portion of the cam lying between the radii CX and CB must be a true arc of a circle struck from center C. Special attention must be paid to this point, because, if the true arc is not maintained between these radii, the full period of rest will not be secured.

5. *Testing.* The testing of the cam is accomplished in the same way as previously described, by the tracing-cloth method. The several positions of the follower in its path should be drawn; and as the cam is rotated into its several positions, if the work has been accurately done, the cam will be perfectly tangent to each position of the follower.

6. *Pressure Line.* By a well-known principle of mechanics, when two bodies are in contact, the line of pressure between them is

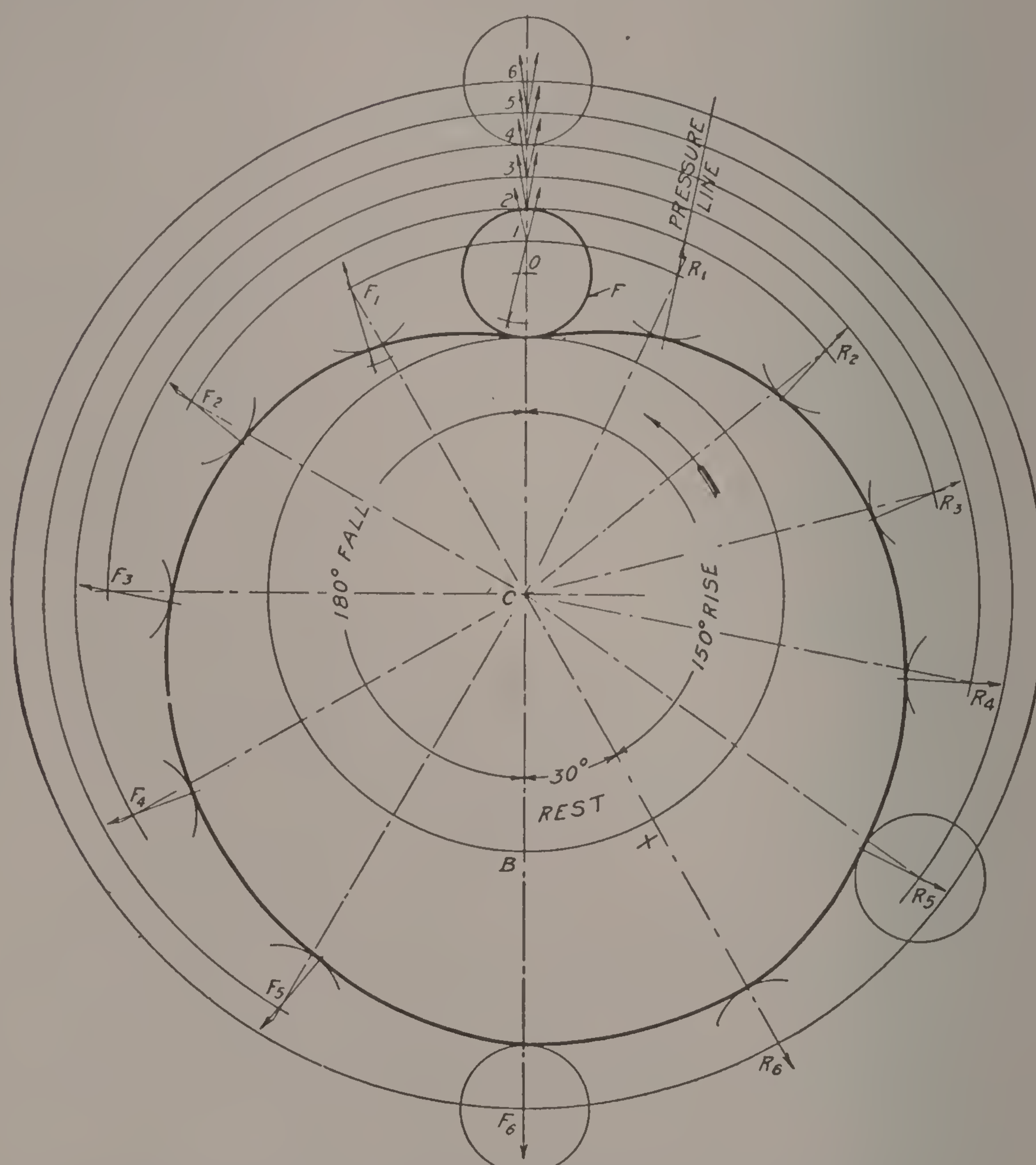


Fig. 81. Diagram of Cam with Roll Follower on Center Line

always perpendicular to the surfaces at their point of contact; in other words, the line of pressure is the common normal at the point of contact. The follower being a true circle, the perpendicular at any point of its surface must pass through the center of the roll; therefore, if we draw a line from the center of each position of the roll to the point of contact between it and the cam, this line will

be the line of pressure between the cam and the roll. This has been done in Fig. 81, and the arrows indicate the direction of the pressure of the cam against the roll. In order to group these lines of pressure so that the action may be clear as the follower moves over its path, the lines of pressure as drawn are rotated back to the corresponding points in the path of the follower. By this it is readily seen that during the period of rise the lines of pressure are all slightly inclined towards the left of the line of travel, while during the period of fall the lines of pressure are all slightly inclined towards the right. The cam as shown in Fig. 81 is a very good cam, so far as the lines of pressure are concerned. The ideal condition would be to have the lines of pressure all coincident with the line of travel. This is impossible, because the only shapes which would give a common normal along the line of travel would be two circles, revolving about their centers, and such a cam could give no travel to the follower. The fact that the lines of pressure are at such a slight angle to the line of travel indicates that there is very little side pressure on the follower and that, therefore, the cam will be an easy working cam.

Example 4. Roll Follower with Path Not Intersecting Cam Center. 1. *Follower Positions.* The follower positions in Fig. 82 are chosen precisely as in Fig. 81, and the subdivisions of the path of the follower similarly made. This case corresponds with that of Fig. 80, the line of travel not intersecting the center of the cam. The shape of the follower, however, is a roll similar to that just discussed in Fig. 81.

2. *Cam Radii.* The original radius CO is drawn as before. Then the radius CX, limiting the arc of rise, the radius CB, limiting the arcs of rest and fall, and the subdivisions of the arcs of rise and fall, are made exactly as in Fig. 81.

3. *Follower Rotation.* The treatment of follower rotation is the same as that in Fig. 80. The intersections R_1, R_2, R_3, etc., being found, the distances R_1L_1, R_2L_2, R_3L_3, which the follower gets ahead of the radii, are set off exactly as in Fig. 80. In this case, however, the points L_1, L_2, and L_3 are the centers of the rotated follower roll; and from these centers are struck the arcs representing the follower roll in its several rotated positions.

4. *Tangent Line.* A smooth tangent line is now drawn to the several positions of the rotated follower, thus giving the outline of

the cam. In this case the outline of the cam giving the period of rest lies between the radii CN_6 and CL_6. In order that the full period of rest may be accomplished, it is necessary that the portion of the cam between these two radii be a true arc, struck from center C. Special attention should be given this point.

5. *Testing.* The cam should be tested by the tracing-cloth method, as before.

6. *Pressure Line.* The pressure lines are drawn as in Fig. 81

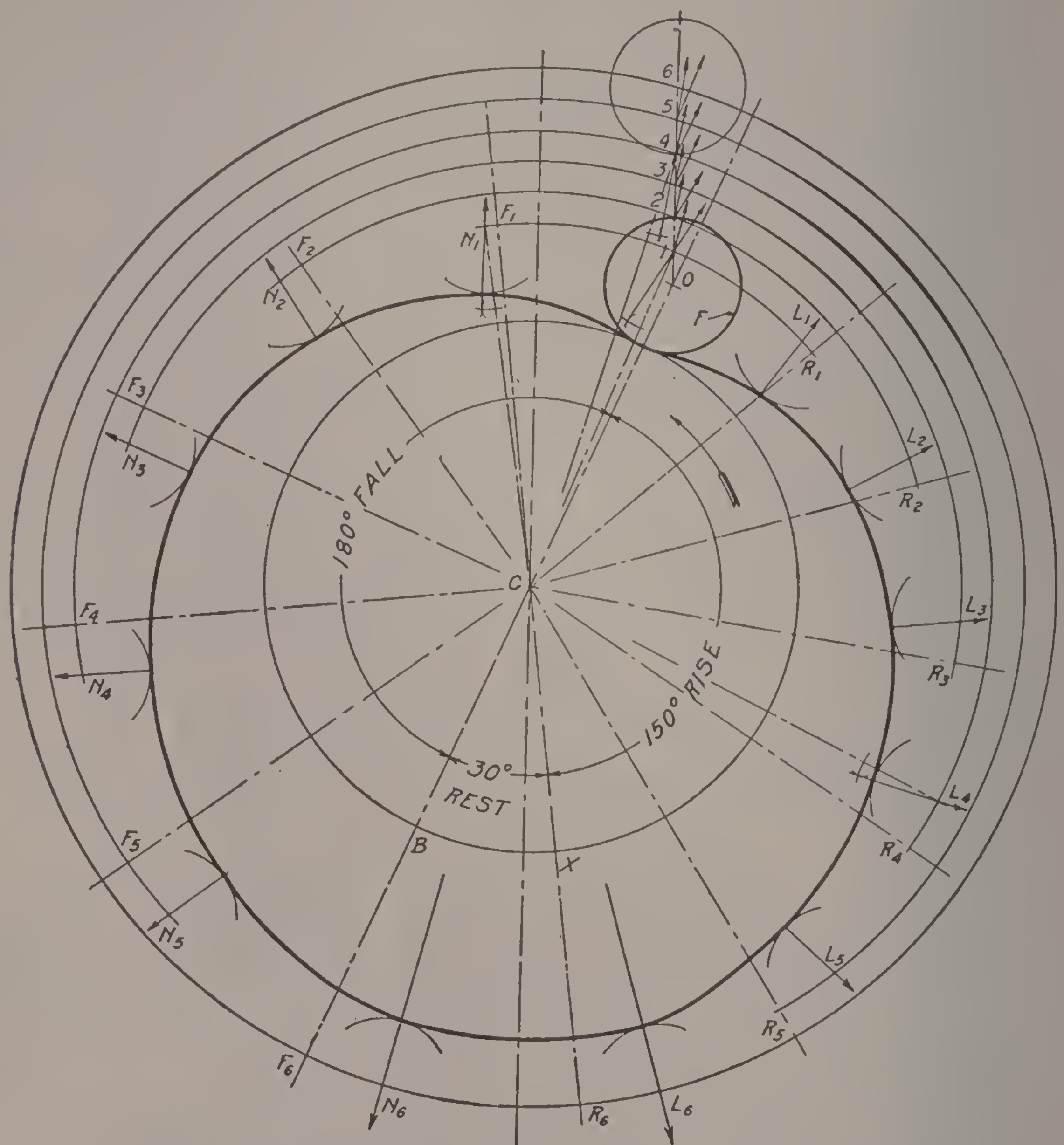


Fig. 82. Diagram of Cam with Roll Follower off Center

by joining the center of the follower roll in its rotated positions to the point of contact between the cam and the roll.

Arrows, as before, indicate the direction of the pressure. These pressure lines may be rotated until they are collected along the line of travel, indicating the change in direction of the pressure between the cam and the roll as the roll passes over its path. A convenient

method of laying off these pressure lines is to join the center of the cam *C* with the center of each roll; measure the angle which the line of pressure makes with this radius; and then transfer the angle to the proper point on the line of travel. This method is clearly indicated in the figure.

As before, it will be seen that the line of pressure lies quite close to the line of travel, and therefore the cam will be an easy working cam.

Example 5. Roll Follower Mounted on Oscillating Arm. *1. Follower Positions.* In Fig. 83 the follower is a roll, as before; but

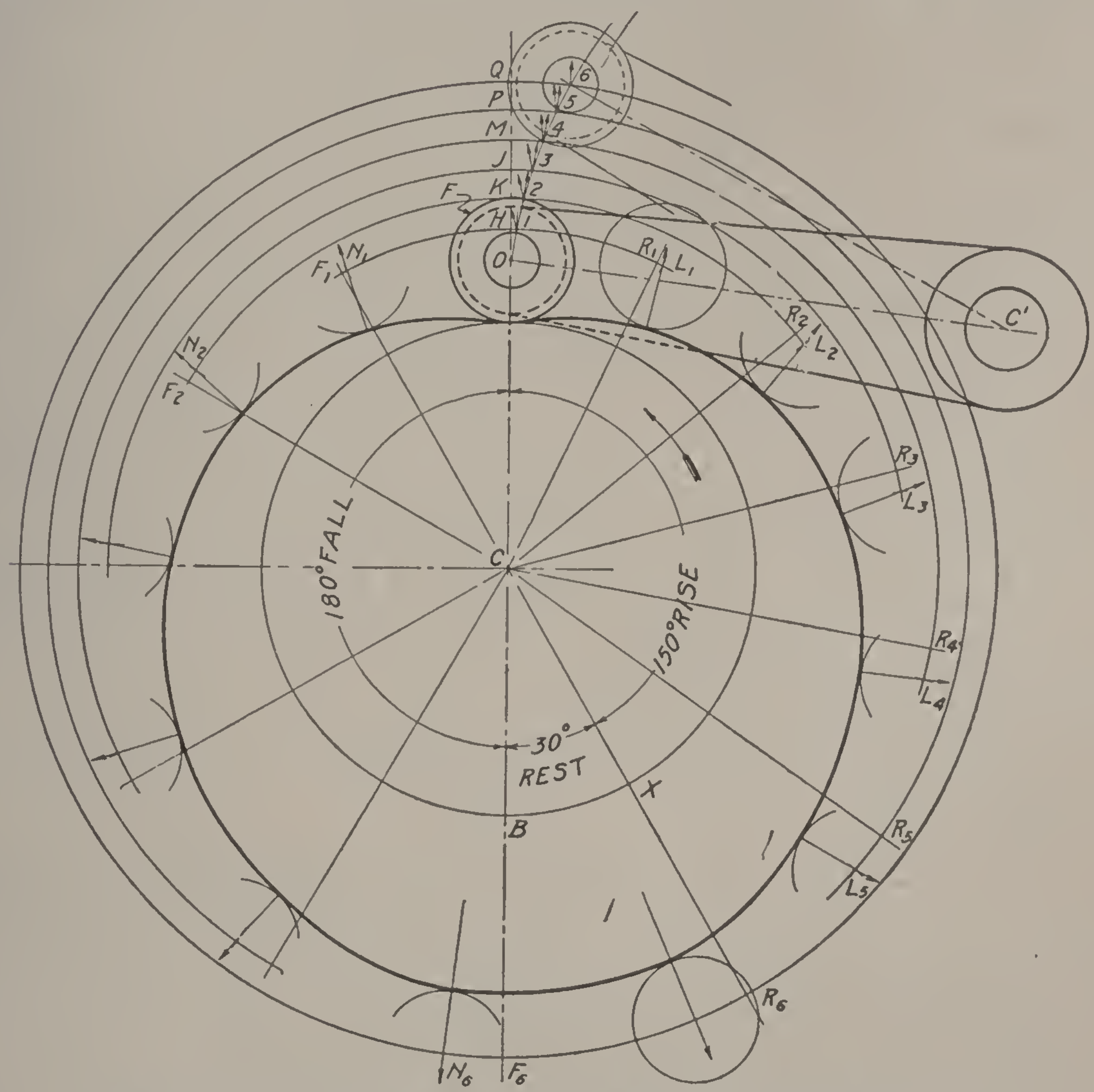


Fig. 83. Diagram of Cam with Roll Follower on Oscillating Arm

instead of traveling in a straight line, it is made to travel along the arc of a circle, being carried on the end of an arm OC', C' being a fixed point about which the arm oscillates. The length of travel $O6$ is the same as before, and is likewise divided into six equal parts. This method of carrying the follower roll is, perhaps, the most common of all, and is a very effective plan for giving the follower roll easy movement along its path.

2. *Cam Radii.* The original radius CO is drawn in this case, as in all the others, through the original center O of the follower roll. The radii CX and CB, limiting the arcs of rise, rest, and fall, are likewise drawn in the given relation to the original radius CO, and the arcs subdivided precisely as before.

3. *Follower Rotation.* For the purpose of follower rotation, arcs are now struck through the points *1, 2, 3, 4, 5,* and *6,* these arcs being prolonged until they meet the original radius in the points H, K, J, M, P, and Q. Then the rotation of the points H, J, K, etc., produces the intersections R_1, R_2, R_3, etc.; but it should be noted in this case that the follower roll, instead of getting ahead of the radius, as in Figs. 80 and 82, is lagging behind it at each position. The distances R_1L_1, R_2L_2, R_3L_3, R_4L_4, R_5L_5, while being laid off equal to *H1, K2, J3, M4, P5, Q6,* etc., as in Figs. 80 and 82, are laid off behind the radius in each position on the arcs of rise and fall. These distances are constantly increasing up to point *6,* where the roll remains stationary during the period of rest, and then constantly decrease to zero, until the roll reaches the original position at point O. From the points just found, arcs are struck as before, the radius being equal to the radius of the follower roll.

4. *Tangent Line.* The tangent line is drawn as a smooth curve to these arcs, and the arc of rest is struck as before, thus developing the outline of the cam.

5. *Testing.* The cams should be tested by the tracing-cloth method as before.

6. *Pressure Line.* The pressure lines are drawn precisely as in Figs. 81 and 82; but it is a little more difficult to rotate these pressure lines back to the points in the path of the follower, and the tracing-cloth method is suggested as best for this purpose. This is done by taking a scrap piece of tracing cloth, fixing a pin through it to the center of the cam, tracing upon it, from the paper below, the pressure lines and the centers of the follower. These centers being rotated back until coincident with the corresponding points of the travel, a second point in each pressure line is pricked through on the paper below. Upon the removal of the tracing cloth, each pressure line can then be quickly drawn through these pricked points and the corresponding centers of the follower, thus enabling the action of the cam to be properly judged.

Example 6. Pointed Follower Mounted on Oscillating Arm. In Fig. 84 the follower roll has been abandoned, and the original pointed follower substituted. The motion of the follower point, however, instead of being in a straight line, is in the arc of a circle precisely as in Fig. 83, except that the follower, being a point instead of a roll, the points L_1, L_2, L_3, etc., have the outline of the cam drawn directly through them. This case is introduced merely for the

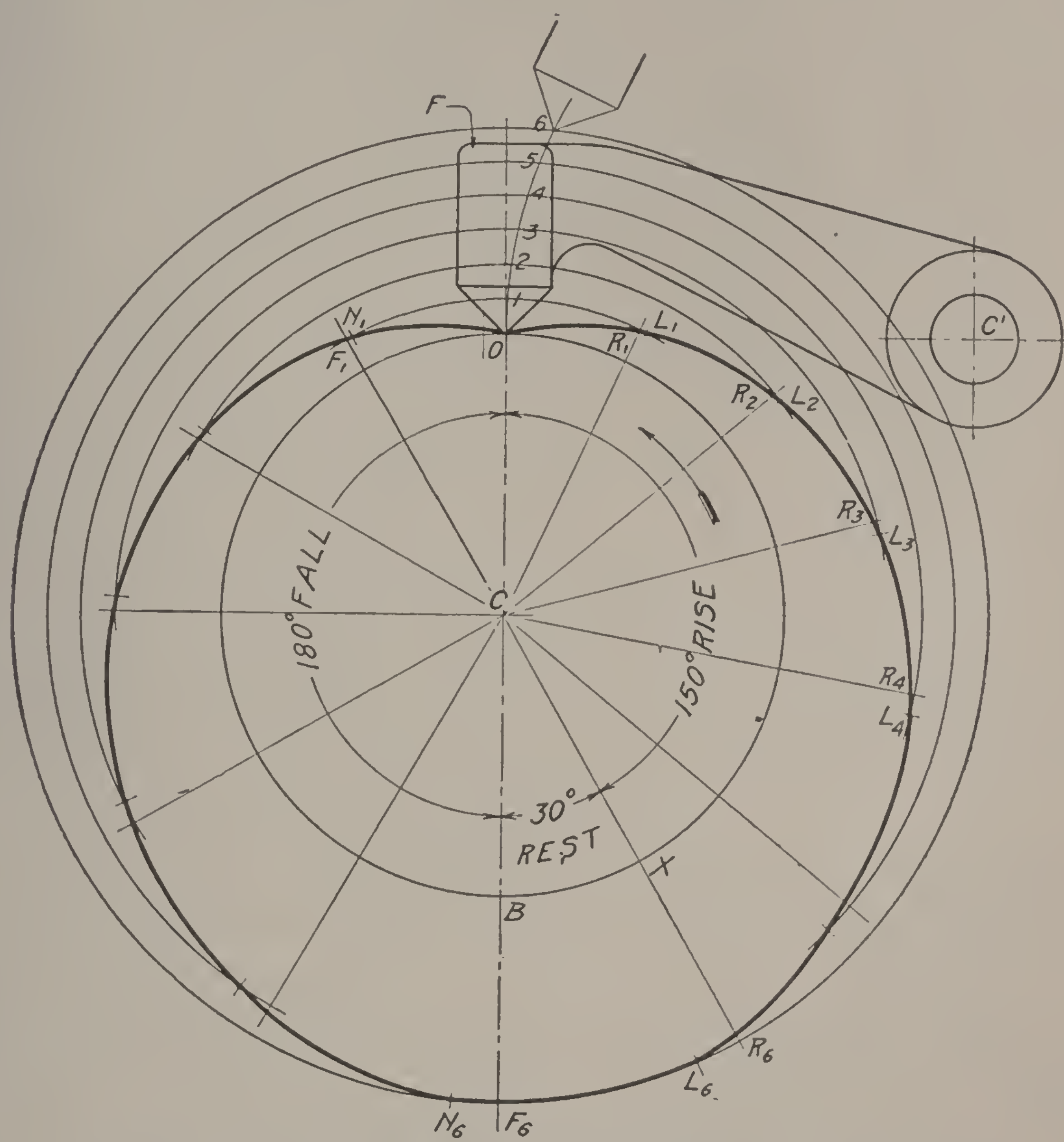


Fig. 84. Diagram of Cam with Pointed Follower on Oscillating Arm

purpose of making the set of cams complete, and it is so closely a counterpart of Fig. 83 that the detail study of it is considered unnecessary.

Example 7. Flat Follower with Path Perpendicular to Working Face. 1. *Follower Positions.* In this example, Fig. 85, is introduced a follower with a flat surface, its path being perpendicular to its working face. The length of its path *06* is the same as before, and is divided into six equal divisions.

2. *Cam Radii.* The point of original contact O being chosen, the original radius OC is drawn perpendicular to it; the radii CX and CB, limiting the arcs of rise, rest, and fall, are then drawn in their proper relation to CO, and the arcs of rise and fall subdivided as before.

3. *Follower Rotation.* The intersections R_1, R_2, R_3, R_4, etc.,

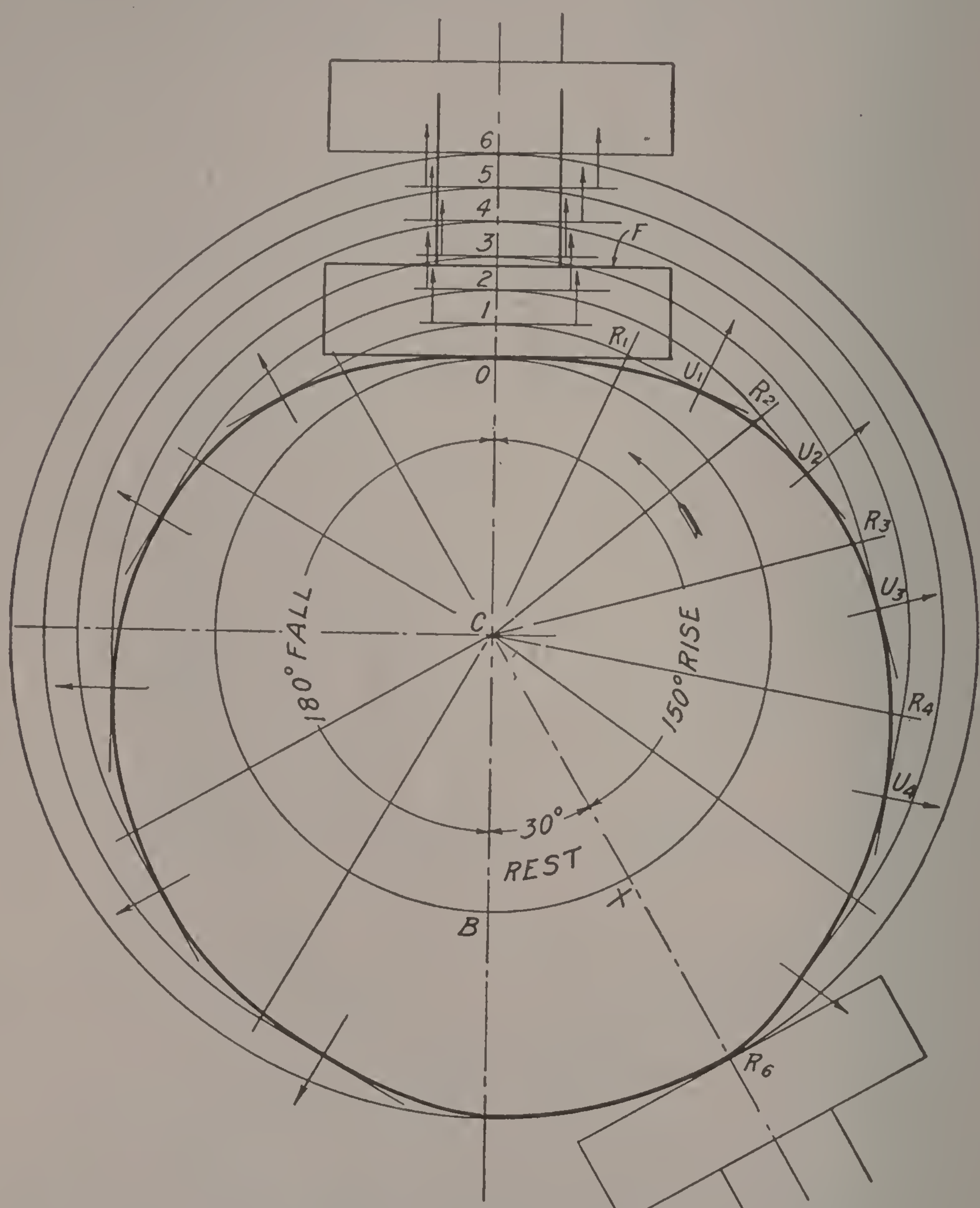


Fig. 85. Diagram of Cam with Flat Follower Perpendicular to Working Face

of the rotating arcs with the several positions of the radii, are found as before. The rotated positions of the follower in this case are obviously represented by drawing perpendiculars to the several radii through the points R_1, R_2, R_3, R_4, etc.

4. *Tangent Lines.* The outline of the cam is produced by

drawing a tangent line to the several lines representing the rotated positions of the follower, the arc of rest being struck as before.

5. *Testing.* The cam should be tested by the tracing-cloth method.

6. *Pressure Line.* Pressure lines are drawn at the points of contact between the cam and the follower, by erecting perpendiculars to the face of the follower at these points. As in the case of the pointed follower, there is considerable friction due to the sliding of the cam along the follower face. This friction produces a side thrust perpendicular to the path of the follower, and modifies the pressure lines slightly. If it were not for this friction, the pressure line obviously would always be perpendicular to the follower face, acting at a point on the follower face some distance to one side of the original point of contact O. By taking the distances $R_1 U_1$, $R_2 U_2$, $R_3 U_3$, etc., to the several contact points, and rotating them back, the manner in which the point of contact between the cam and the follower moves along the face of the follower during its travel can be conveniently studied; it is seen that the point of contact during the arc of rise moves to the right of the original radius, and gradually swings back again until, at the point *6*, it is on the line of the original radius. During the arc of rest, the point of contact remains at point *6*; during the arc of fall, it moves to the left of the original radius, finally coming back again to the original point of contact O.

Example 8. Flat Follower Mounted on Oscillating Arm. 1. *Follower Positions.* In this example, Fig. 86, a flat-faced follower is carried by an oscillating arm similar to the roll in Fig. 83. The length of travel $O6$ is divided into six equal parts, as in the previous cases, the positions of the follower being indicated by the radial lines $C'1$, $C'2$, $C'3$, etc.

2. *Cam Radii.* The original radius CO is drawn through the assumed point of contact, and perpendicular to the face of the follower in its original position. The radii CX and CB are then drawn limiting the arcs of rise, rest, and fall, and the subdivisions of the arcs of rise and fall properly made.

3. *Follower Rotation.* The intersections R_1, R_2, R_3, etc., of the rotating arcs are found as in the previous cases. The rotation of the follower is accomplished by drawing through the points R_1, R_2, R_3, etc., straight lines making the same angle with these radii as

the follower in its corresponding positions makes with the original radius *CO*. For example, the angle a_1 is equal to a; the angle b_1 is equal to b; and the angle c_2 is equal to c.

4. *Tangent Line.* The tangent line is now drawn to the several positions of the rotated follower, and the arc of rest is struck, thus giving the outline of the cam.

5. *Testing.* The cam should be tested by the tracing-cloth method.

6. *Pressure Line.* The pressure lines are drawn the same

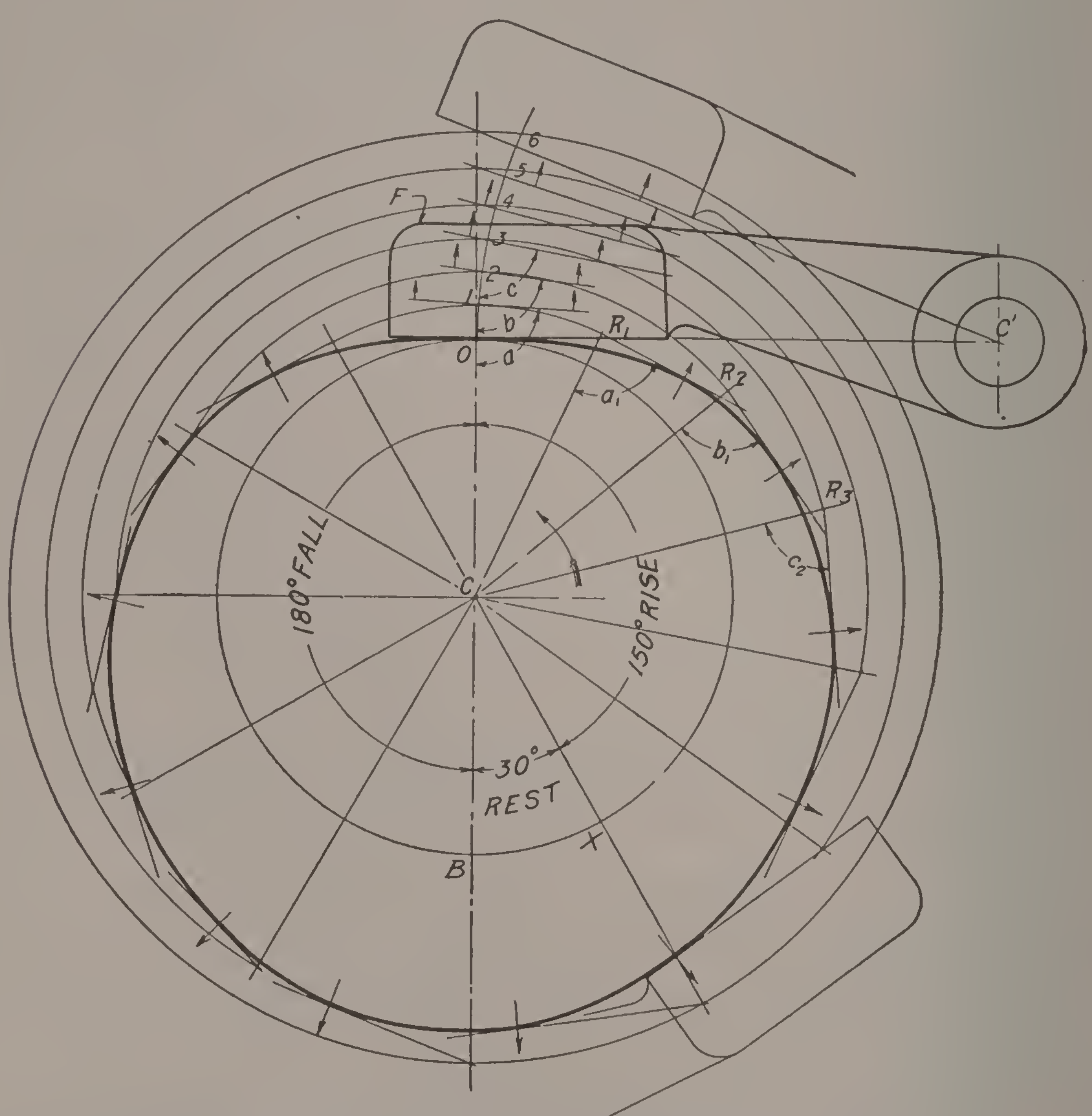


Fig. 86. Diagram of Cam with Flat Follower on Oscillating Arm

as in Fig. 85, and it is suggested that the rotation of them back to the positions of the follower in its path be accomplished by the tracing-cloth method, as in Fig. 83.

Design of Complicated Cams. It should be especially noted, that in all the cases of cams thus far studied, the methods of procedure are absolutely identical. In the more complicated cases of cams which follow, and others which may arise in the designing of

special machines, the same principles apply, however much they may apparently be disguised by the conditions of the problem. A good method to follow in designing a complicated cam is first to study the cam by the tracing-cloth method, as described on page 84. After an approximate outline of the cam has been determined as being possible, and giving about the motion of the follower desired, then the more formal method of rotating the follower about the cam can be applied, to give the exact outline. It should be remembered that it is not possible to reproduce by cam movements all combinations of length of travel, angle of rest, rise, and fall, as fixed by the conditions of the problem. In such cases the cam is designed to give the nearest possible approach to the motion desired, or some of the working conditions are changed.

In each of the cases considered, it has been assumed that the follower is always held against the surface of the cam, either by its own weight or by a spring. Another method of accomplishing this is to make a cam with two surfaces, the follower running between them in the groove thus formed.

Plate Cams with Complex Motions

Uniform Motion. All cams thus far considered are of the uniform-motion variety, that is, having equal rise in equal time. This means that each fraction of the travel of the follower is made in the same time as each other similar fraction; and likewise, that each fraction of the rotation of the cam is made in the same time as that of any other fraction of its movement. In further explanation of the term "uniform motion", suppose a railway train to travel ten miles in twenty minutes, the speed of the train being the same during each minute; it would travel $\frac{1}{2}$ mile in each minute, and would have a uniform speed or velocity of $\frac{1}{2}$ mile per minute. Under such conditions the train would be moving at the full speed of $\frac{1}{2}$ mile per minute, both at the beginning and at the end of the ten miles. If, however, it had exactly ten miles to travel and exactly twenty minutes to do it in, and must be at rest at the beginning and at the end of the given time, it could not gain its full speed in an instant or lose it in an instant, but must start and stop gradually. Therefore, during the first part and the last part of the time, it would be moving at a speed slower than $\frac{1}{2}$ mile per minute, and must go faster than $\frac{1}{2}$ mile per minute during the middle part of the run, to make

up for the time lost in starting and stopping. Such motion would not be uniform. The more suddenly the train starts and stops, the more nearly uniform the main part of the travel may be, but the greater the shock when starting and stopping.

Suppose we have a piece to be moved one foot in ten seconds; if the motion is to be uniform, the piece would have a velocity of $\frac{1}{10}$ foot per second. If the piece is light and the mechanism which does the moving is sufficiently powerful, the piece may be made to start and stop almost instantly without serious shock, and consequently may have practically uniform motion.

Variable Motion. If the mechanism which moves the piece be so designed as to start and stop it gradually, the shock will be avoided. We may have a gradual increase of speed at the start, until full speed is attained; then a uniform full speed during the main part of the stroke; and finally a gradual decrease of speed to a full stop at the end of the stroke; or the speed may increase during the entire first half of the stroke, and decrease during the entire last half, the motion at no time being uniform. The first condition is used where the piece is doing work during the stroke, as, for instance, the cutting stroke of a tool; and the second condition, wherever quick motion is desired without regard to its character, so long as it is without shock.

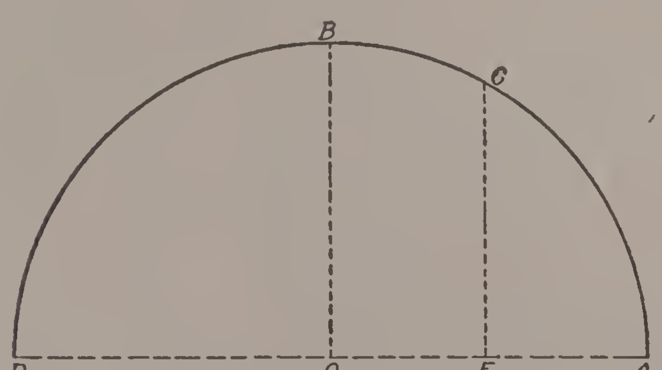


Fig. 87. Harmonic Motion Diagram

Harmonic Motion. In Fig. 87, let the semicircle *ABD* represent the path along which a piece moves with a uniform velocity. Now, if we have another piece moving along the diameter *AD*, starting from *A* at the same time as the first piece, and moving at such speed that a perpendicular let fall from any position of the first piece to the line *AD* will locate the second piece—that is, when the first piece is at *C*, the second piece is at *E;* when the first piece is at *B*, the second is at *O;* and so on—then the piece which travels along the line *AD* has harmonic motion. It moves slowly at first, increases to a maximum speed at the center, and decreases to rest at the end. This motion is quite common for shaper rams, slotters, and feed-mechanisms. Cams can readily be designed to give such a motion.

Uniformly Accelerated and Retarded Motion. A piece which has uniformly accelerated and uniformly retarded motion (see article on Mechanism) moves through one unit of space in the first unit of time, three the second, five the third, seven the fourth, nine the fifth, etc., to the middle of its stroke, then decreases at the same rate to the end of the stroke. For example, if a piece is to move with uniformly accelerated and retarded motion one foot in ten seconds, it will move $\frac{1}{50}$ foot the first second, $\frac{3}{50}$ the second, $\frac{5}{50}$ the third, $\frac{7}{50}$ the fourth, $\frac{9}{50}$ the fifth, when it will have traveled $\frac{1}{50}+\frac{3}{50}+\frac{5}{50}+\frac{7}{50}+\frac{9}{50}$ $(=\frac{25}{50})$, or $\frac{1}{2}$ the whole foot in one-half the whole time, the speed increasing all the time; at the end of the fifth second, when half the distance has been traveled, it begins to slow down, and travels $\frac{9}{50}$ the sixth second, $\frac{7}{50}$ the seventh, $\frac{5}{50}$ the eighth, $\frac{3}{50}$ the ninth, and $\frac{1}{50}$ the tenth. The rate at which the velocity increases during the first half of the time is often made the same as that at which the velocity of a weight increases when dropped from a height; and the rate at which the velocity decreases during the last half of the time, the same as that at which the velocity of a weight decreases if thrown straight up into the air. This particular form of uniformly accelerated and uniformly retarded motion is, therefore, known as gravity motion. It is commonly produced by cams, although not often used for motions greater than a few inches.

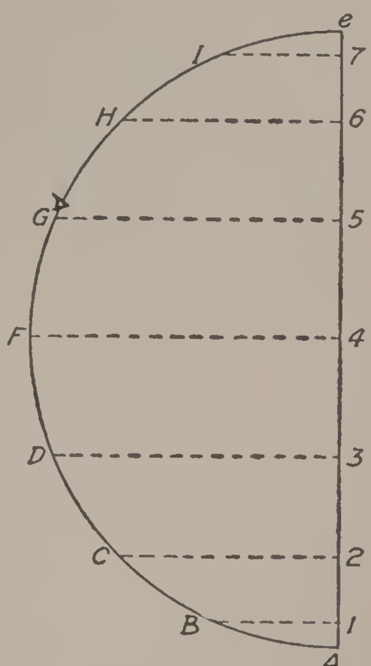


Fig. 88. Semicircle Showing Harmonic Steps

If in Fig. 79 it had been required to raise and lower the follower with harmonic instead of uniform motion, the only difference in procedure would have been in dividing up the path *06*. The divisions of *06*, instead of being equal, would be found as shown in Fig. 88. Suppose the line *Ae* to be the same length as *06*; on this line as a diameter, draw a semicircle, and divide this semicircle into as many equal parts as the arc of rise is divided. In this case, suppose the arc of rise to be divided into 8 equal parts; then the semicircle is likewise divided as shown in the figure. From the points *B*, *C*, *D*, etc., drop perpendiculars to the line *Ae*, cutting it at points *1*, *2*, *3*, etc. For the first eighth of the arc of rise of the cam, let the follower rise

the distance *A-1*, for the second eighth the distance *1-2*, for the third eighth the distance *2-3*, and so on. Such motion of the follower is harmonic motion.

If it is required that the follower shall rise and fall with uniformly accelerated and retarded motion, the method of dividing the line of travel *Ae* is shown in Fig. 89. As in the case of harmonic motion, suppose the arcs of rise and fall each to be divided into 8 equal parts. Now, the line *Ae* must be divided into 8 parts, but these parts must be such that, beginning with the point *A*, the distances *A-1*, *1-2*, *2-3*, and *3-4* shall be in the ratio of 1, 3, 5, and 7; and the distances *4-5*, *5-6*, *6-7*, and *7-e* shall be in the ratio of 7, 5, 3, and 1; in other words *A-1* is $\frac{1}{32}$ of the whole line *Ae; 1-2* is $\frac{3}{32}$ of *Ae*, *2-3* is $\frac{5}{32}$ of *Ae*, and so on. To divide up the given length *Ae* so that the divisions may bear the above relation to one another, draw the line *Ar* at any convenient angle, and, choosing any convenient distance as a unit, mark it off on this line 32 times, beginning at *A*. From *I*, the last of these dividing points, draw a line to *e;* next find the point *B*, the first division from *A; C* the third from *B*, *D* the fifth from *C*, *E* the seventh from *D*, *F* the seventh from *E*, *G* the fifth from *F*, *H* the third from *G;* and through the points *H*, *G*, *F*, *E*, etc., draw lines parallel to *Ie*, cutting the line *Ae* at *7*, *6*, *5*, *4*, etc. It is obvious that *Ae* is then divided in the same proportion as *AI*, and if the follower were made to travel along the line *Ae* according to these divisions, it would have uniformly accelerated and retarded motion.

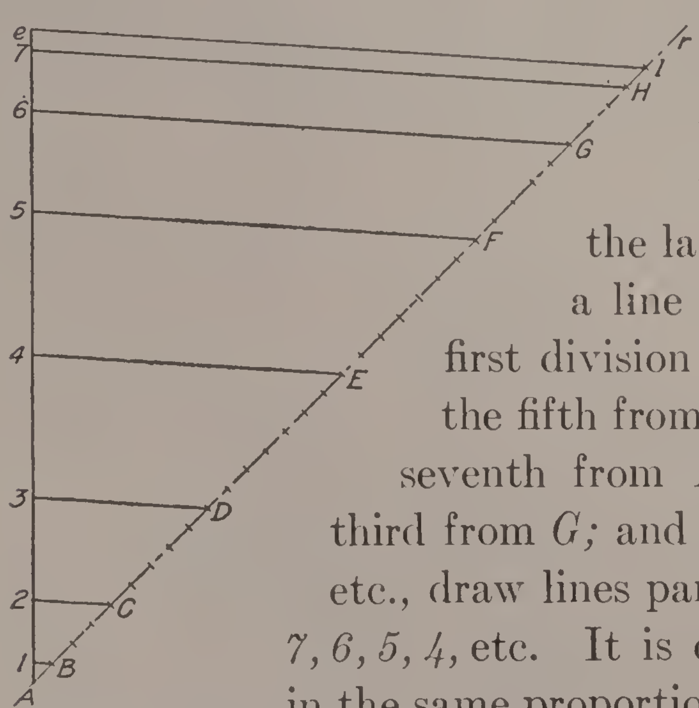


Fig. 89. Method of Dividing Line of Travel

Practical Example of Complex Motion Cam. For the purpose of illustrating these principles, suppose it is required to design a plate cam, Fig. 90, such that the follower rises from point *A* to *e*, with harmonic motion, while the cam rotates through 120°; it is then to remain at rest during the cam movement of 60°; it is then to fall to its original position with a uniformly accelerated and retarded motion, while the cam turns through 150°; it is then to remain at rest while the cam rotates through the remaining 30°, when the same

cycle of movement is to be repeated as long as desired. This is briefly expressed as follows:

Harmonic rise. . . . . .120°
Rest. . . . . 60°
Uniformly accelerated and retarded fall. . . . . .150°
Rest. . . . . 30°

1. *Follower Positions.* The length of travel *Ae* being known, it is divided for purposes of the rise, by the principles of Fig. 88, into

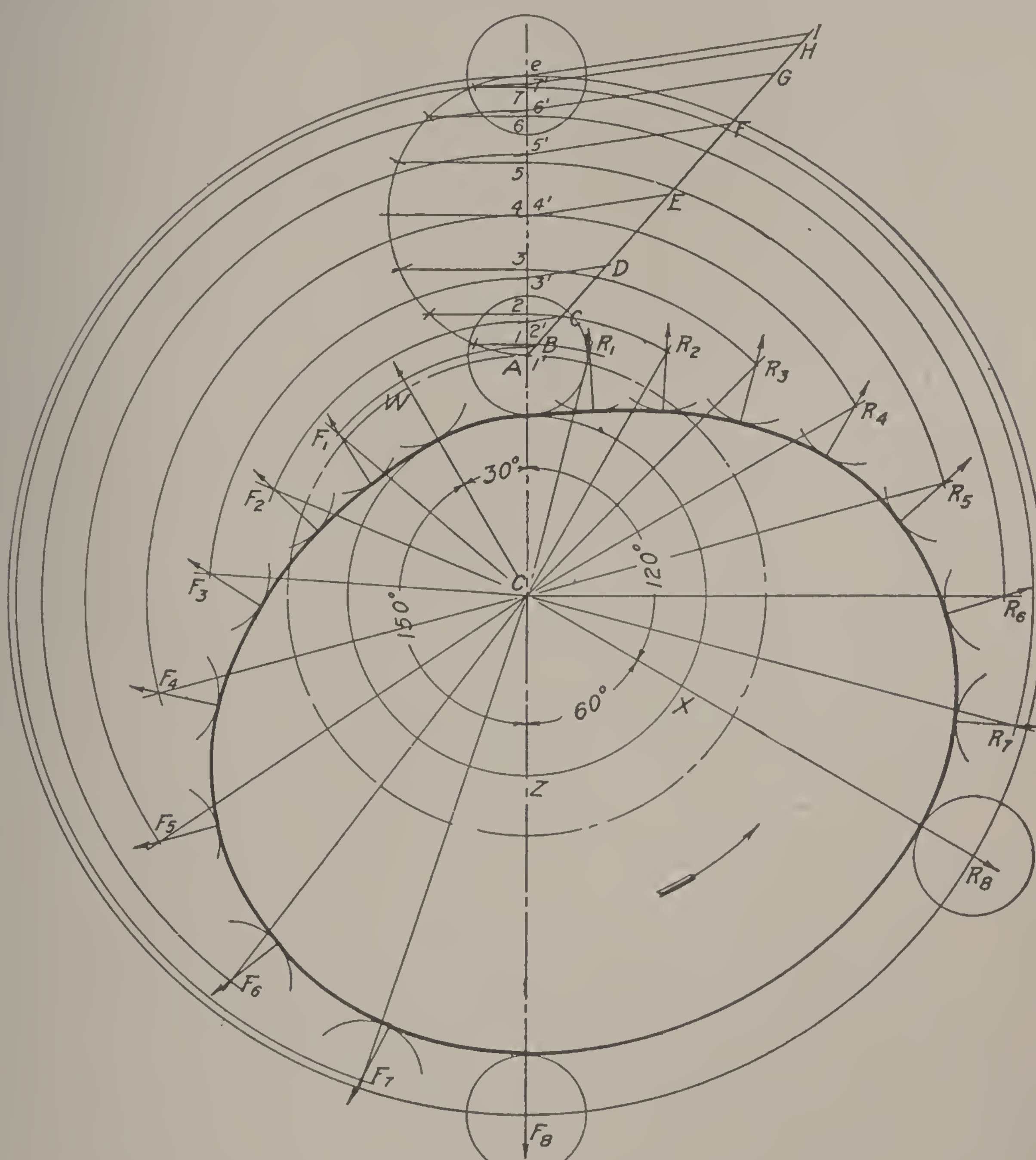


Fig. 90. Diagram of Complex Motion Plate Cam

distances giving harmonic motion of the follower; and for purposes of the fall, by the principles of Fig. 89, into distances giving uniformly accelerated and retarded motion. Eight spaces are chosen, so that the process of making these divisions is an exact repetition of the method in Figs 88 and 89.

2. *Cam Radii.* The diameter of the base circle being chosen, and, for the purpose of this problem, the center being assumed in line with the path of the follower, draw the original radius CA, then the radii CX, CZ, and CW, limiting the arcs of rise, rest, and fall respectively. As 8 divisions of the follower path have been chosen, the arcs of rise and rest must each be divided into 8 equal divisions. It should be observed that while the divisions are equal throughout each arc, the arc of fall being different from the arc of rise, the divisions of the arc of fall are not equal to the divisions of the arc of rise, measured on the base circle.

3. *Follower Rotation.* The rotation of the follower about the cam, for the period of rise, is accomplished by striking arcs through the points *1, 2, 3, 4, 5, 6, 7*, and e, making the intersections R_1, R_2, R_3, R_4, R_5, R_6, R_7, and R_8, with the cam radii. The rotation of the follower about the cam, for the period of fall, is accomplished by striking arcs through points $1'$, $2'$, $3'$, $4'$, $5'$, $6'$, $7'$, and e, making the intersections F_1, F_2, F_3, F_4, F_5, F_6, F_7, and F_8, with the cam radii. These points of intersection represent the centers of the follower roll in its rotated positions, and from these centers should be struck arcs with a radius equal to the radius of the follower roll.

4. *Tangent Line.* A smooth curve is now drawn tangent to these small arcs, thus forming the outline of the cam.

5. *Testing.* The cam may be tested by the tracing-cloth method, precisely as in the cases already developed.

6. *Pressure Lines.* The pressure lines are found in exactly the same manner as in Fig. 81, and can be rotated back to the points in the path of the follower, in order to conveniently study the change in direction of the pressure lines as the follower moves along its path.

It should be noted that in Fig. 90 the same method of procedure is followed as in Figs. 79 to 86, except that the determined points in the path of the follower do not make equal divisions of the path, as in the case of uniform motion.

Translation Cams

Rotating plate cams, like those thus far considered, are most commonly met with in practice. A straight-line, reciprocating motion of a plate, however, may be made to produce similar follower movements, in which case the cam is known as a translation cam. A straight-line movement is equivalent to movement along an arc

with infinite radius. With this understanding, the same principles may be made to apply to translation cams as to rotating cams.

Development of Translation Cam. Suppose it is required to produce the same movement of the follower as in Fig. 90, by means of moving a plate in a straight line instead of rotating it. This case is shown in Fig. 91.

1. *Follower Positions.* The same follower motion being required as in Fig. 90, the path is laid out exactly in the same way, the follower positions for the rise along path $D8$ fulfilling the requirement of harmonic motion, and for the fall along path lF_8, fulfilling the requirements of uniformly accelerated and retarded motion. This is shown in the figure, and it is observed that no change from the method of Fig. 90 is employed.

2. *Cam Radii.* The base circle does not exist in this case as a circle, but has become a straight line, and may be chosen of any length, say Dx. The cam radii, being always perpendicular to the

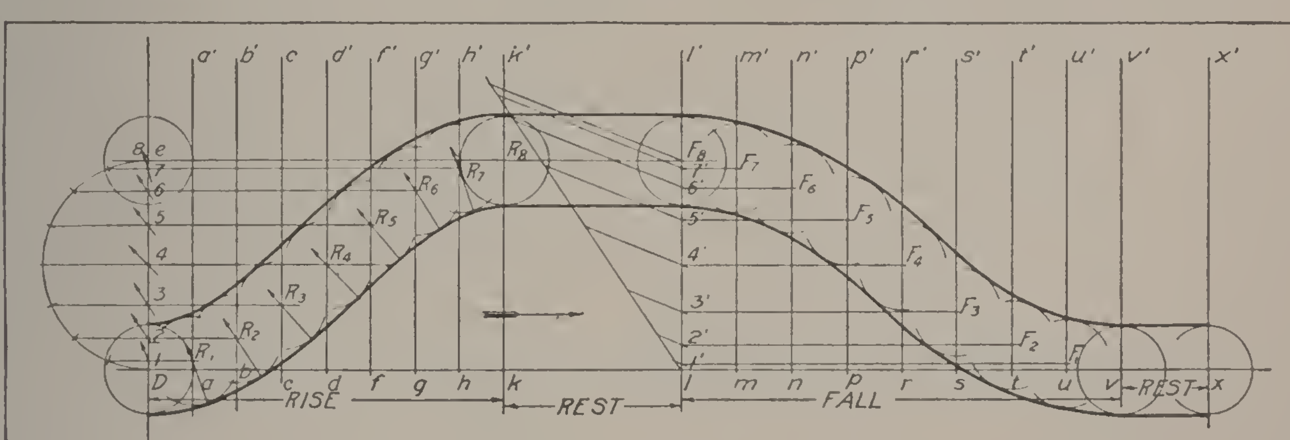


Fig. 91. Diagram Showing Development o fTranslation Cam

cam arc (in this case the straight line Dx), become parallel lines, perpendicular to Dx. The cam arc of rise in Fig. 90 is now represented in Fig. 91 by the distance $D8$, which should fulfill the relation $\frac{Dk}{Dx}=\frac{120}{360}$; in order to make the same relative movement of cam during rise as in Fig. 90, Dk should likewise be divided into 8 equal parts. The arc of rest in Fig. 90, being $\frac{1}{2}$ the arc of rise, the distance kl in Fig. 91 is made $\frac{1}{2}$ the distance Dk. The arc of fall in Fig. 90 being $1\frac{1}{4}$ the arc of rise, the distance lv in Fig. 91 is made $1\frac{1}{4}$ the distance Dk. The final arc of rest in Fig. 90 being $\frac{1}{2}$ the first arc of rest, the distance $v\,x$ in Fig. 91 is made $\frac{1}{2}$ the distance kl. This completes the cycle; and the parallel lines aa', bb', cc', etc., drawn through the

several points of division as noted, represent the several positions of the cam radii.

3. *Follower Rotation.* Since the lines of follower rotation are all perpendicular to the cam radii—which in this case are all parallel—the rotation, or translation, of the follower is accomplished by drawing parallel lines through the determined points of the path, producing the intersections R_1, R_2, R_3, R_4, etc. Between points R_8 and F_8, the follower rests; and for the period of fall, the intersections F_8, F_7, F_6, F_5, etc., are determined as for the rise, by producing the parallel lines through the points in the path of fall. From point v to x the follower again rests. These intersections represent the centers of the follower in its translated positions.

Now, with a radius equal to the radius of the follower roll, arcs are struck to represent the outline of the follower in each of its translated positions.

4. *Tangent Line.* A smooth curve is now drawn tangent to the several translated positions of the follower roll. In this cam a new feature is introduced by drawing these tangent lines on both sides of the roll, thus making a groove which holds the follower firmly in position at all times. This gives an absolutely positive fall to the follower roll. The same grooved construction might have been made on any of the cams heretofore studied, instead of allowing the follower to come down by gravity or by the force of a spring.

5. *Testing.* The cam may be tested by the tracing-cloth method as before, the procedure in this case, however, being one of translation instead of rotation. The original radius, with the follower in its several positions being traced upon the cloth, is set upon each of its translated positions, and, by careful inspection, it is noted whether the roll, in this position, just touches the faces of the cam groove as drawn.

6. *Pressure Line.* The pressure lines are drawn precisely as in all cases thus far considered, and may be translated back to the path of the follower in order to study their direction as the follower moves along its path.

Although the same cycle of follower movement has been accomplished in this case as in the rotating cam, Fig. 90, the translation cam is not in position to begin a repetition of the cycle by further movement. If we reversed the motion of the cam, the cycle also

would be reversed; and in the cam under discussion we should have a rest, then a uniformly accelerated and retarded rise, then a rest, then a harmonic fall, the periods of time being reversed as well as the motion. We could, of course, by choosing the motion for rise and fall exactly the same, secure the same motion for the reversed as for the forward movement of the cam.

Cylindrical Cams

Development of Cylinder Cams. Suppose that the outline of the translation cam as developed in Fig. 91 be wrapped around a cylinder whose circumference is exactly equal to Dx, and that the lines represent a spiral groove cut into the surface of the cylinder. If, then, a follower roll be allowed to remain in this groove while the

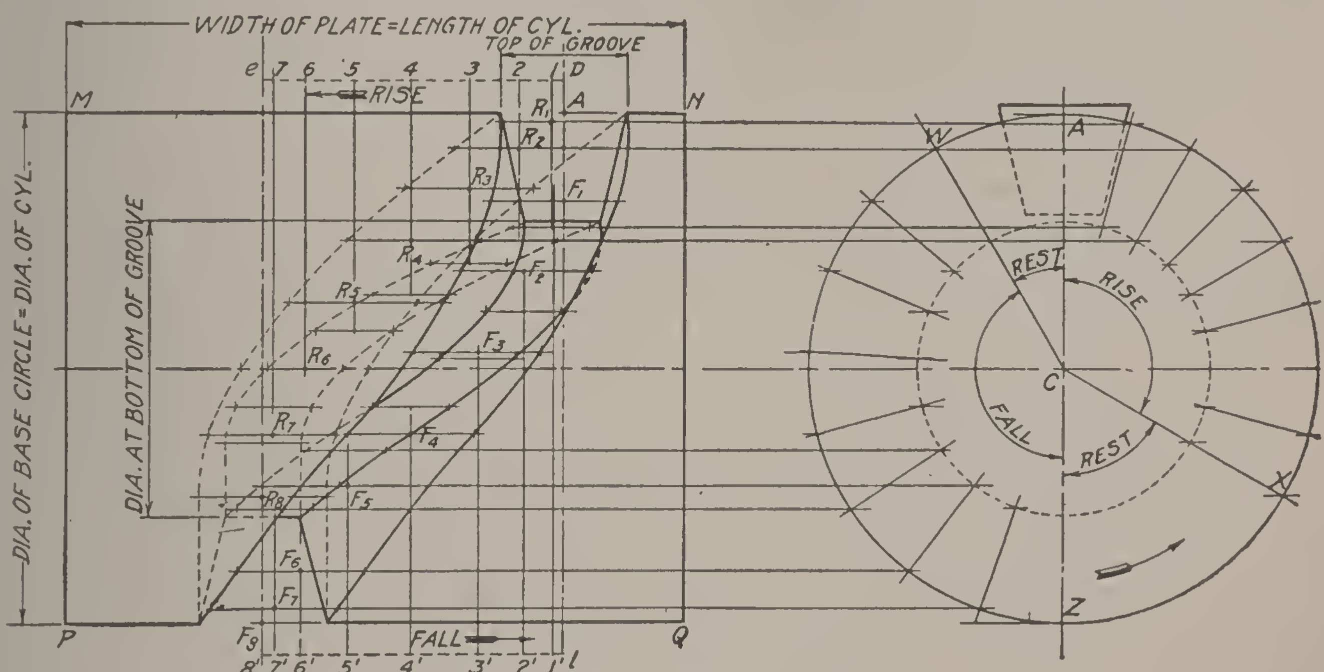


Fig. 92. Development of Cylindrical Cam

cylinder is rotated on its axis, the cycle of follower movement will be repeated as long as we choose to rotate the cylinder. Such a grooved cylinder is known as a cylindrical cam.

Fig. 92 shows a cylindrical cam in two projections. Attention is called to the tapering follower roll used. This is because it is necessary that points on the sides of the groove and the surface of the roll have the same velocity about the center C. The roll, therefore, must be the frustum of a cone whose apex is at C.

The top of this groove is produced by wrapping Fig. 91 around the surface of the cylinder as previously described. The bottom of the groove is produced by making a translation cam whose base line is equal in length to the circumference of the cylinder at the bottom

of the groove, and then wrapping it around that cylinder. This base line for this smaller cylinder is divided into the same number of parts as the line Dx, the divisions, however, all being proportionally smaller. The length of the follower path, and its divisions, are in nowise different from those shown in Fig. 91; and the method of developing the outline of the cam is precisely the same.

The wrapping of these translation cams, for purposes of the drawing, is accomplished by means of dividers and compasses, according to the principles for the development of cylinders, as explained in Mechanical Drawing, Part III.

The limitations of construction of cylindrical cams are considerably greater than those of the simpler rotating cams; and it is more frequently a question of experiment and trial to get the proper surfaces, than it is of exact theoretical layout on the drawing board.

BELTING

Cams and gears transmit positive motion from the driver to the follower by direct contact of the surfaces. As the distance between

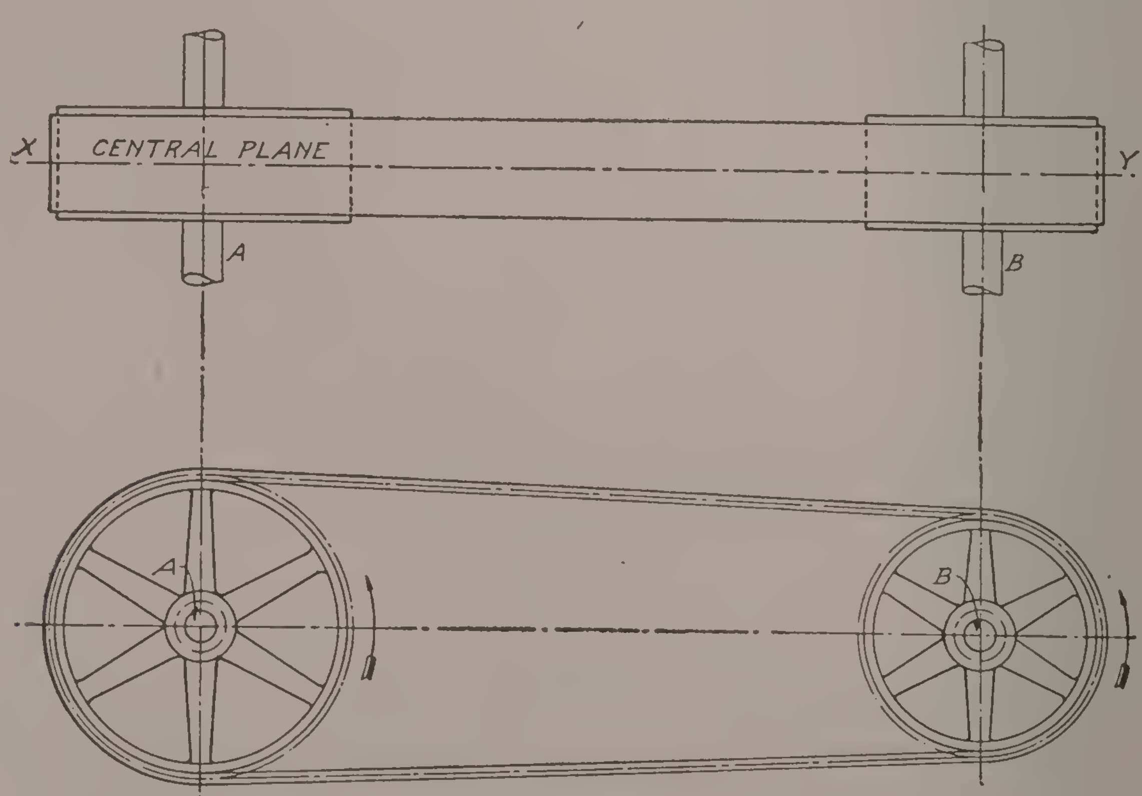


Fig. 93. Diagram of Simple Open Belt Drive

centers of shafts increases, the driver and follower for such methods of transmission become large, unwieldy, and costly, and rigid links may be used to connect the rotating pieces, as in the case of parallel

rods of a locomotive. For a further increase of distance, the transmission is attained by means of belts and pulleys, and, if the distance is very great, by wire ropes and sheaves. As there is always some slipping of the belt (from 1 to 2 per cent), the velocity ratio is not exact; but this is not essential in many classes of machinery. The slip and stretch of the belt reduce the shock when heavy machinery is set in motion—an important feature in many cases.

Open and Crossed Belts. The simplest forms of belt drives are the open belt (Fig. 93) and the crossed belt (Fig. 94). In each

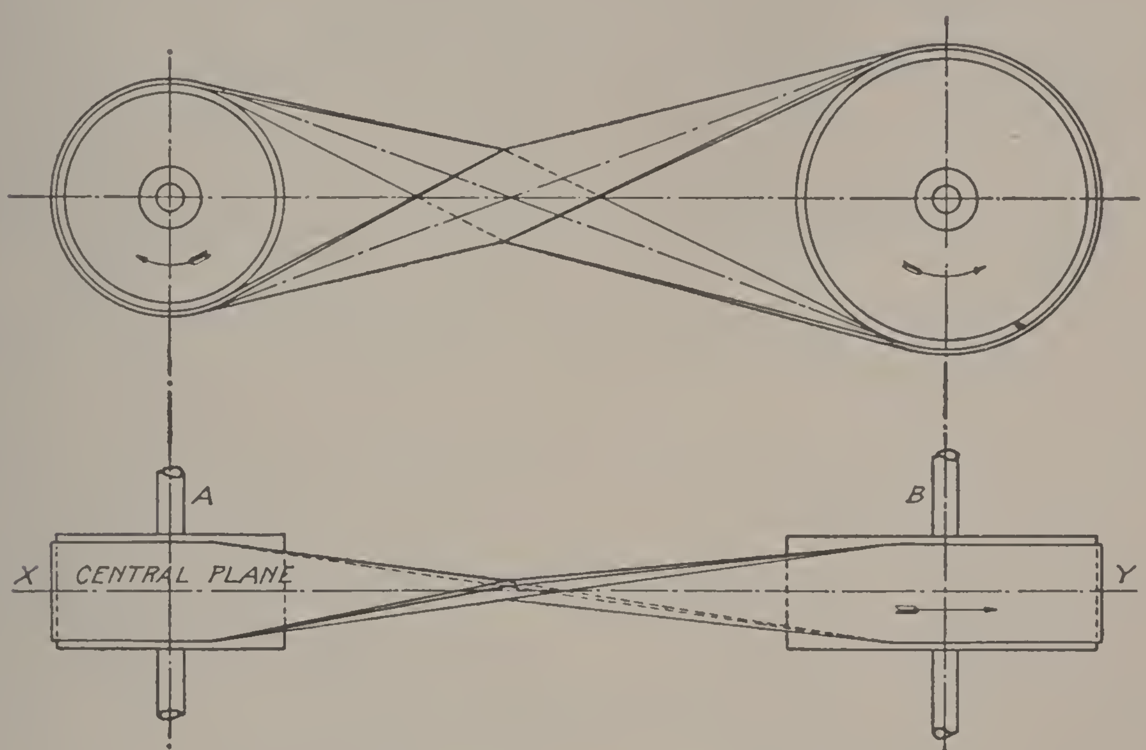


Fig. 94. Diagram of Simple Crossed Belt Drive

case the shafts are parallel, and the pulleys fastened to the shaft with set screws or keys. The central planes of the pulleys must obviously be coincident. The belt is then tightly stretched over the pulleys, and, assuming B, the driver, to turn in the direction of the arrow, motion will be transmitted to A, on account of the friction set up between the belt and pulley surfaces. The fibers of the belt, in running on or off the pulley, bend over one another, so that those next the pulley, on the inside of the belt, are compressed, while those on the outside are stretched. Assuming the compression and stretch to be equal, then the central fiber does not change in length. This central fiber is shown in the figure by a "dash-and-dot" line. Considering that there is no slip of the belt on the pulley, the face of each

pulley will move exactly with the belt, and the turns of each pulley will depend on its circumference; or,

$$\text{Turns of } A = \frac{\text{Speed of belt}}{\text{Circumference of } A} = \frac{S}{\pi \times \text{Diameter of } A}$$

$$\text{Turns of } B = \frac{\text{Speed of belt}}{\text{Circumference of } B} = \frac{S}{\pi \times \text{Diameter of } B}$$

$$\text{Velocity ratio} = \frac{\text{Turns of } A}{\text{Turns of } B} = \frac{\text{Diameter of } B}{\text{Diameter of } A}$$

Thus the velocity of the shafts is inversely proportional to the ratio of the diameters of the pulleys. The action of the belt in bending about its central fiber has the effect of increasing the diameter of the pulley by an amount equal to the thickness of the belt, and an exact calculation for velocity ratio must take this fact into consideration. For example, suppose that the diameters of A and B are 8″ and 24″ respectively, and that the belt is $\frac{1}{4}$″ thick. Then the velocity ratio is $\frac{24}{8}=3$ for the *usual* approximate calculation; but $\frac{24.25}{8.25}=2.939$ for the exact value.

The direction of shaft rotation depends on the method of applying the belt. In the case of the open belt, the top surfaces of each pulley being connected, each shaft rotates in the same direction; while in the case of the crossed belt, the top surface of A being connected to the bottom surface of B, the shafts rotate in opposite directions. Thus the directions of rotation are the same when the center line of belt lies wholly on one side of the line connecting the centers of pulleys; and different when it intersects the line of centers.

Crowning Pulleys. Suppose that a flat belt is placed on the side of a double cone, Fig. 95, and that we start to rotate the cone in the direction of the arrow. The edge E, which is stretched more tightly than F, has a greater grip on the surface of the cone, and will climb up the incline as shown by the dotted lines. With continued rotation of the cone, the belt, if not prevented, will move farther up the incline, will finally pass the crest, and start down on the other side until the two edges E and F have equal tension, or the pull to the right is balanced by an equal pull to the left. The center line of the belt will now run in the central plane XY of the pulley.

As long as this condition is maintained, the belt will run true and will stay on the pulley. Also, if the pulley faces were perfectly

flat, the belt a perfectly homogeneous piece of leather, and the shafts perfectly parallel, the belt would stay in the pulley. Such perfect conditions, however, cannot be produced or maintained, and it is therefore necessary in practice to imitate the conditions of Fig. 95, and "crown" either one or both pulleys, so that the belt will not develop any tendency to run off. On the contrary, it will constantly seek to keep its center line in the central plane of the pulleys, any tendency of one edge to slacken and run off being instantly counteracted by the tightening up of the other as it starts to climb, thus pulling the belt back until the balance is secured. A very slight amount of crowning will accomplish this result, and as little crown as possible, consistent with good running, should be provided, that too great inequality of tension in the belt may not be introduced.

In Fig. 93, if the shafting be not parallel, the center line of the belt will not run in the central plane of the pulley, and the belt will climb towards the high part of the pulley, as in the above case of the cone, and we may expect the belt to run off.

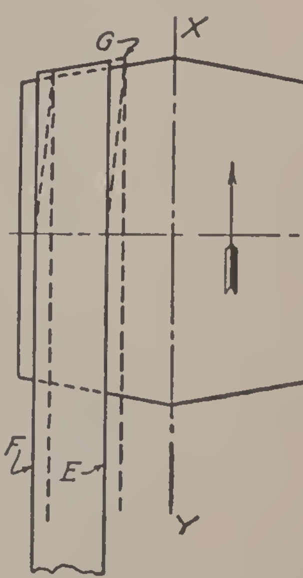


Fig 95. Theory of Crowning a Pulley

The above discussion reduces to one fundamental working condition for belt transmission, viz, *The center line of the belt leaving a pulley must lie in the central plane of the pulley to which the belt is delivered.*

This principle is applicable to all cases of belt transmission, however complicated, whether the shafts be parallel or at an angle. The use of guide pulleys is merely a means of controlling the delivery of the belt according to the principle. The student should commit this principle to memory, and go over its application until he is sure that he understands it; for without it he cannot solve complicated belt problems, and he cannot feel sure of his solution of even the simplest ones. In the pages of discussion and illustration which follow, the student should constantly note the recurrence and application of this principle, as it is really all there is to the solution of belt problems, except familiar knowledge of how to make the drawing projections, which he already is supposed to possess.

Tight and Loose Pulleys. Tight and loose pulleys are provided for cases in which a machine is to be thrown in and out of service without stopping the driving shaft.

A common arrangement is shown in Fig. 96, where a pulley with a straight face is located on the line shaft, and two pulleys with crowned faces are on the countershaft. Pulley *B* is loose on the shaft, and *C* is fast to the shaft. A collar *D* is placed on left of *B*, to prevent its end motion. Shifting the belt is accomplished by pushing on the advancing side of belt, close to the receiving pulley.

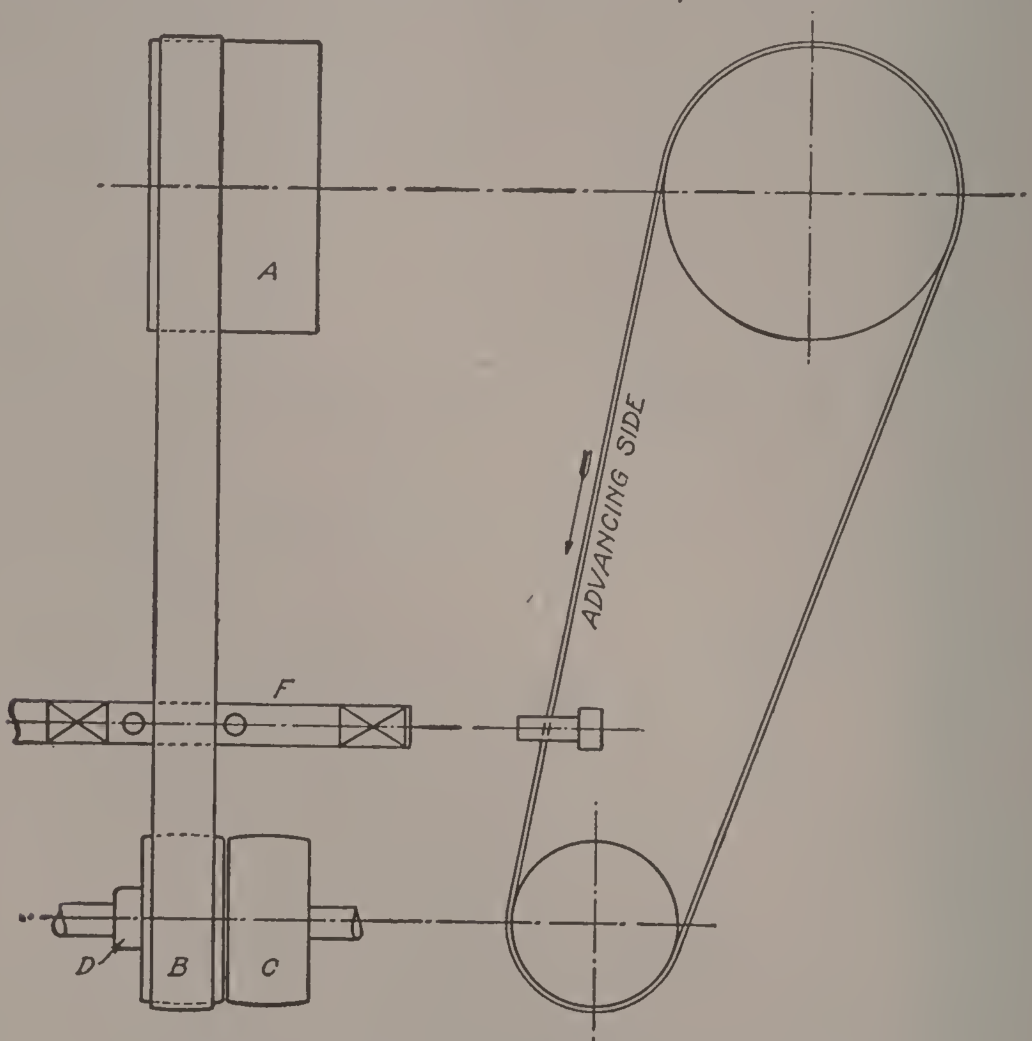


Fig. 96. Diagram of Tight and Loose Pulley Drive

The shifter *F* has two iron pegs, one on each side of the belt, and is operated by hand. The belt is readily guided by pressure on the advancing side, for the motion of the receiving pulley aids the motion of the belt; but if pressure were applied to the retreating side it would be necessary to use enough force to shift the belt bodily sidewise on the face of the pulley. As excessive tension on the belt decreases its life, the diameter of the loose pulley is often slightly decreased, thus permitting the belt, when doing no useful work, to be under less tension than when driving.

Another arrangement is to provide a clutch to throw into a loose pulley on the line shaft, the belt standing idle when not in service.

Shafts Not Parallel. Suppose an open belt to connect pulleys A and B_1, on parallel shafts, Fig. 97.

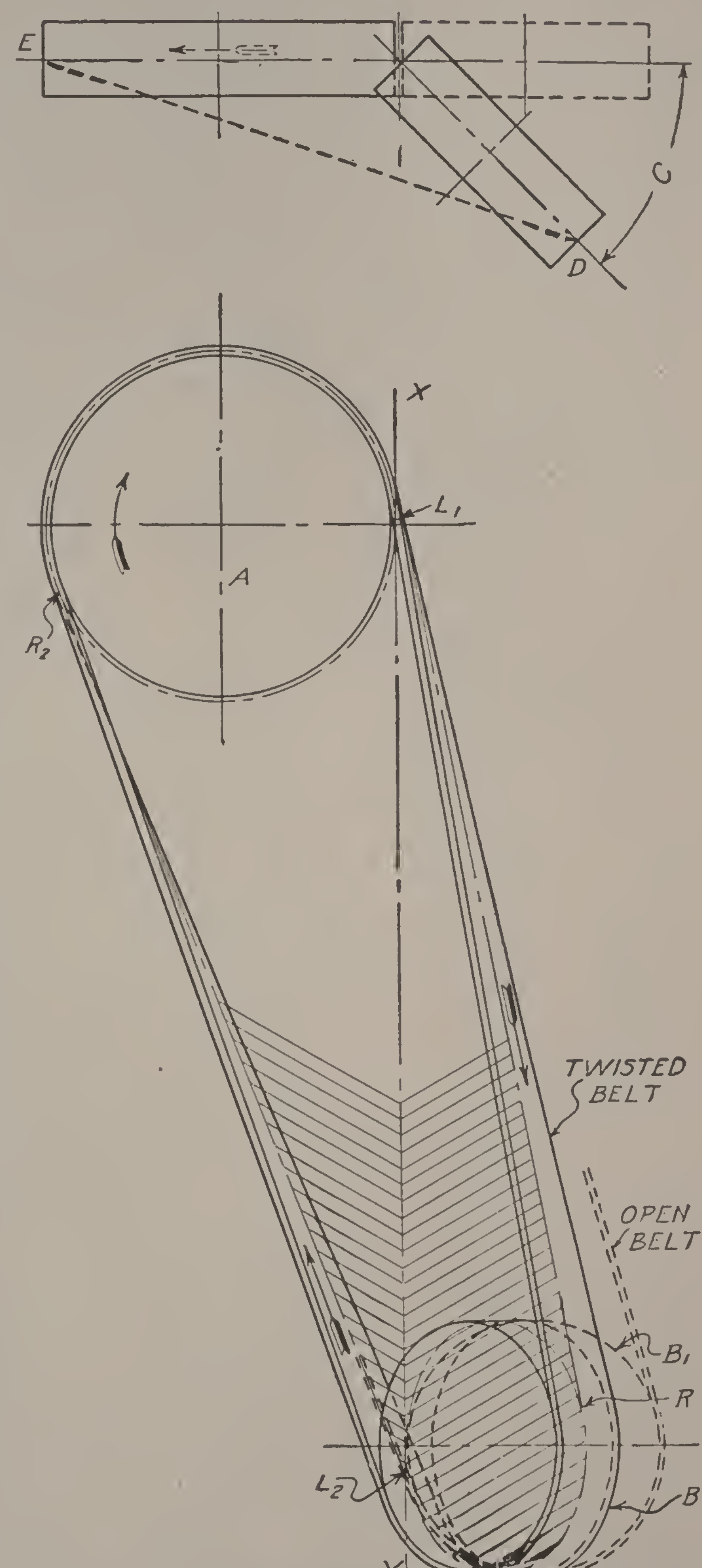


Fig. 97. Diagram of Pulley Drive where Shafts Are not Parallel

Draw a tangent XY to the pitch circles of the pulleys at the points L_1 and L_2, where the belt leaves the pulleys. Now rotate the central plane of the pulley B_1, about XY as an axis, through any angle C, to position shown by pulley B. The central planes (shaded) of pulleys A and B intersect on the line XY, called the trace of the planes. The axes are now not parallel, but the belt may be made to run in one direction, for it still obeys the general principle of the guiding of belts; *i.e.*, the center line of the belt, on leaving the driving pulley, is delivered into the central plane of the receiving pulley.

Examining the figure, we find that the center line of the belt moves in direction of arrow from L_1 to R, and around pulley B to L_2, from L_2 on the surface of B to R_2, thence on surface of A to L_1, the starting point. From the point L_1, where the belt leaves A, until it reaches R, the center line of the belt is in the central plane of the receiving pulley B, and the

belt twists about this line, presenting a flat side to the face of pulley B at R.

From L_2, where the belt leaves B, until it reaches R_2, the center line of the belt is continually in the central plane of the receiving pulley A, and a similar twist in the belt takes place. If now we attempt to reverse the direction of motion of the belt, the top of pulley A, moving in the direction of the dotted arrow, would carry point D of the center line of belt to the left-hand edge of A, as indicated by the dotted line DE, where it would drop off. Therefore, this belt drive for shafts not parallel is suitable only for motion in one direction.

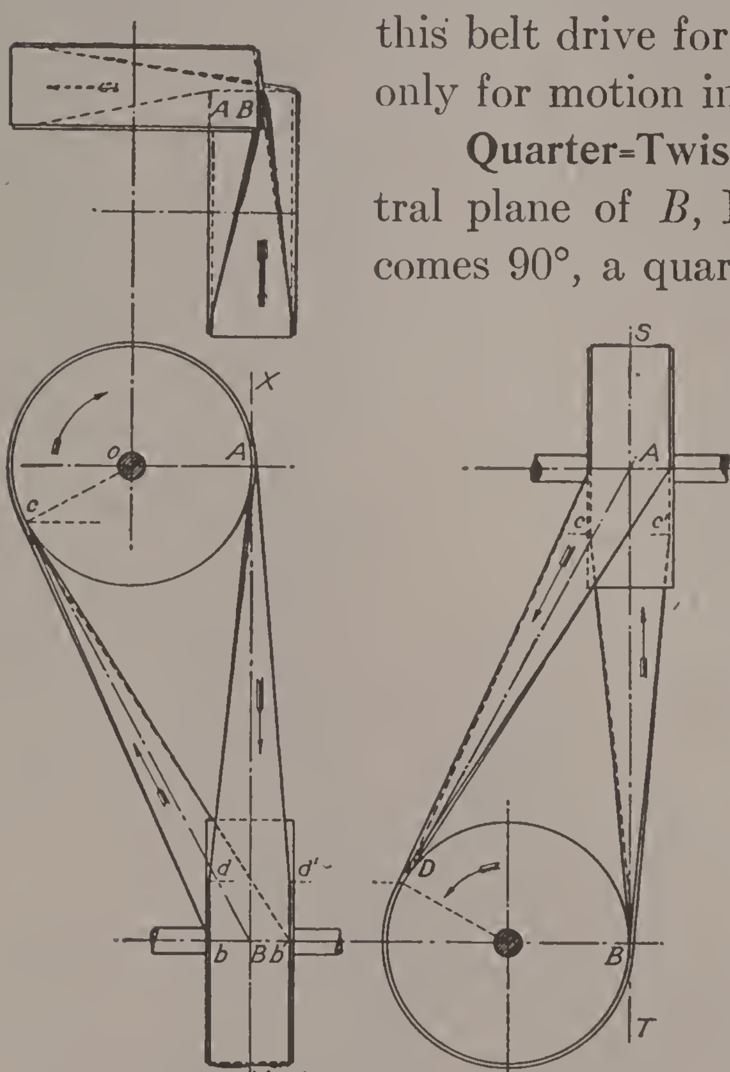


Fig. 98. Diagram for Quarter-Twist Belt

Quarter-Twist Belt. By rotating the central plane of B, Fig. 97, until the angle C becomes 90°, a quarter-twist, or half-crossed belt, Fig. 98, is obtained; and if angle C becomes 180°, the crossed belt of Fig. 94 is the result.

If the thickness of belt is neglected, it will be noted that the central plane of B (Fig. 98), which is represented by the trace XY, is tangent to the surface of pulley A; and similarly on the side view, the trace ST of the central plane of A is tangent to the surface of B. Now follow the center line of belt in the direction of the arrows on the front and side views, starting at point A, where the belt leaves the upper pulley. From A to D, and around to the back of pulley B, the center line is shown in the trace XY of the front view. From B, where the belt leaves the lower pulley, to c, and around to the front and starting point A, the center line is shown in the trace ST of side view. Therefore the center line of the belt is always delivered into the central plane of the receiving pulley, and it will drive satisfactorily in the direction of the arrows. Reversing

the motion will cause the belt to run off the pulleys, as in the previous case.

The belt should always be put on so that the same side of the belt touches both pulleys when it is possible to do so. In making the drawing of the belt we shall call the side of the belt which touches the pulleys the inside, and the other side the outside. Now, referring first to the left-hand elevation in Fig. 98, where the belt lies around the circumference of the upper pulley, from the point c, where the upward-moving part of the belt strikes the pulley, around to A, where the downward-moving part leaves the pulley, only the edge of the belt is visible, and is represented by drawing an arc of a circle from line oc around to oA, with a radius equal to the radius of the pulley plus the thickness of the belt. The location of c may be found closely enough for all practical purposes, by drawing a line from B tangent to the upper pulley, c being the point of tangency, and oc the radius drawn through c. In drawing the arc of the circle from oc to oA, it is well to let it run by these lines a little way in the pencil drawing, and that part which is not used may be erased after the drawing is inked. The descending part of the belt leaves the pulley at A; and from that point to the place where it strikes the lower pulley, it twists through an angle of 90°, coming out over the front of the lower pulley. The edge of the belt, which we see in its full thickness where it leaves the upper pulley at A, twists toward the left, less and less of it being seen as the belt descends, until at d, where it strikes the other pulley, the two corners of this edge coincide, and from there to the bottom of the pulley we see this edge of the belt as a line. At the same time that the thickness of the belt has been disappearing from view, the outside of the belt has been coming into view, until at dd' we see the full width of the belt, the outside corner being the one which is visible. The inside corner is behind the rest of the belt, and while it may be shown dotted in the drawing, it is usually omitted entirely. From d' to the bottom of the pulley the two right-hand corners coincide. Points d and d' are found by drawing the horizontal dotted line through D (side view), and laying off on this line a distance equal to one-half the width of the belt each side of line XY. From ee' the belt goes around the back side of the pulley to bb', where it begins to be drawn off to the left, bb' being on the center line drawn through

the shaft, since, by glancing at the right-hand view, we can see that the upward-moving part of the belt leaves the lower pulley at B, which is on a level with the center of the shaft. After leaving *bb′*, the belt remains behind the pulley for a short distance, and is shown dotted. It is projected at its full width at *bb′*, but as soon as it leaves the pulley it begins to twist toward the right, the left-hand edge gradually coming into view until it is seen at its full thickness where it strikes the pulley at *C*. At the same time, the inside face of the belt, which is toward the front when the belt leaves the pulley, gradually turns toward the right, and appears narrower until it disappears from view—that is, projected as a line. This completes the front view, and the side view is drawn according to the same principles, as is also the plan view.

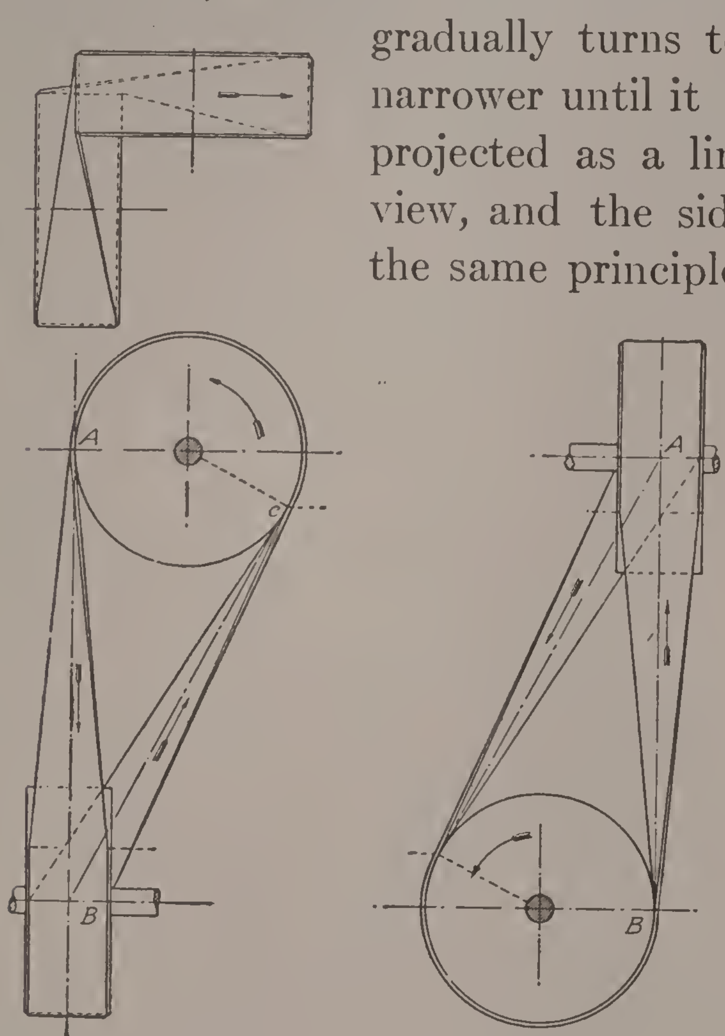


Fig. 99. First Variation from Fig. 98 for Quarter-Twist Belt

To be strictly correct, the sides of the belt should be shown curved at *A* and *B*, for the belt is pliable and starts to curl and slip sidewise a short distance above these points. In order not to have an excessive side slip, the angles *c B A* and *D A B* should not be more than 25°.

Figs. 99 and 100 show what changes are made in the location of the pulleys and the appearance of the belt by changing the direction of rotation of the shafts. In Fig. 99 the lower shaft turns in the same direction as in Fig. 98, but the upper shaft turns in the opposite direction. In Fig. 100 the upper shaft turns in the same direction as in Fig. 98, and the lower shaft turns in the opposite direction.

Reversible Quarter-Twist. *Two Guide-Pulleys.* In order to reverse a quarter-twist belt, it will be necessary to introduce one or two guide-pulleys to bring the center line of the belt at all times into the central plane of the receiving pulley. Fig. 101 shows an

arrangement where two guide-pulleys are used. Let the driving pulley R and the driven pulley P be located as in the case of the quarter-twist belt of Fig. 99. Suppose that the direction of rotation is but seldom reversed, and that the usual motion of the driver is in the direction of the arrow. The part of the belt which has the greater load should have a direct connection between R and P, leaving the slack side to run over the guide-pulleys, thereby decreasing the stress on the belt and lessening the friction in the journals of the guide-pulleys.

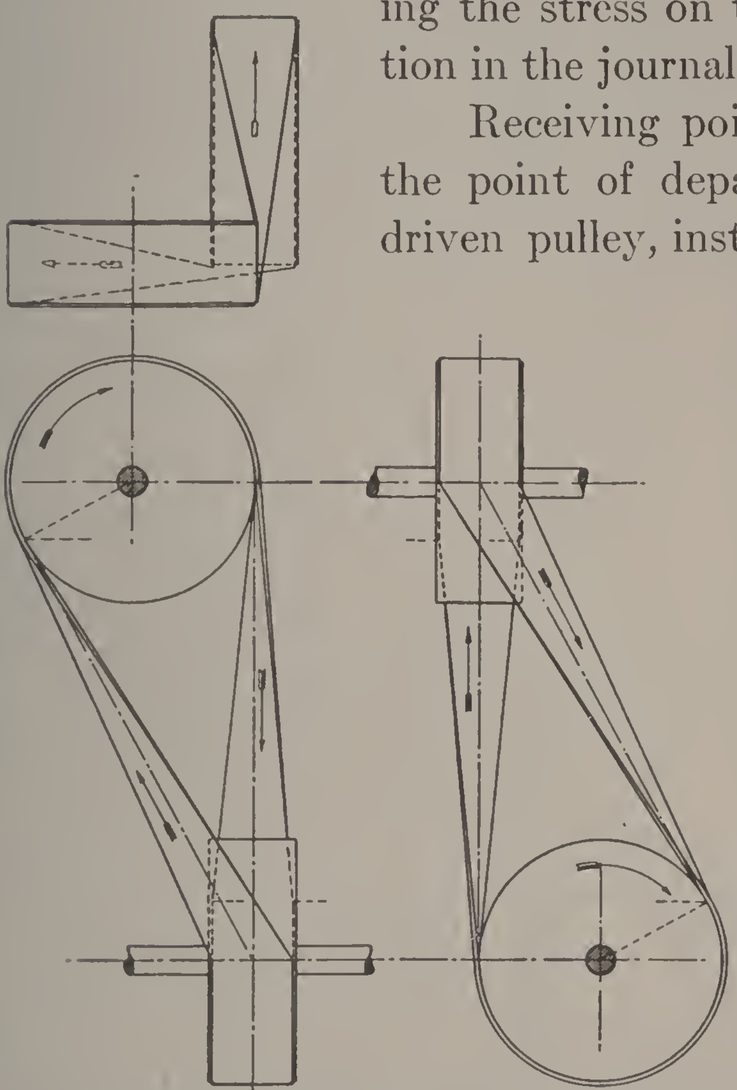


Fig. 100. Second Variation from Fig. 98 for Quarter-Twist Belt

Receiving point A is then connected to B, the point of departure from the back of the driven pulley, instead of over to the front face, as in case of Fig. 99; and the belt twists about this line as an axis through an angle of 90°, so as to present flat sides to both pulleys. The plan view of the center line of the belt is the line of intersection AB of the traces of the central planes of R and P. Evidently the belt will run in either direction along the trace of either plane. From the point of departure D of the driving pulley, the belt must be led to the receiving point E of the driven pulley, by means of guide-pulleys. Draw DE for the plan view of the central plane of the guide-pulleys. This plane is perpendicular to the paper, and its traces or intersections with the central planes of R and P are shown in XY and DH of the front view.

The guide-pulleys are idlers introduced only to form a path for the belt, and do not in any way affect the velocity ratio. They may, therefore, be made of any convenient size to suit the existing conditions. We may then assume on the plan view, that J and K are points on the axes of the pulleys M and N, and draw the guide-pulleys so that the face of M bisects the front face of P at E, and

one face of *N* bisects the right-hand face of *R* at *D*. On the front and side views, the location of the axes has been assumed as *GG* and *FF*, and the corresponding views of the pulleys are drawn according to the principles of projection.

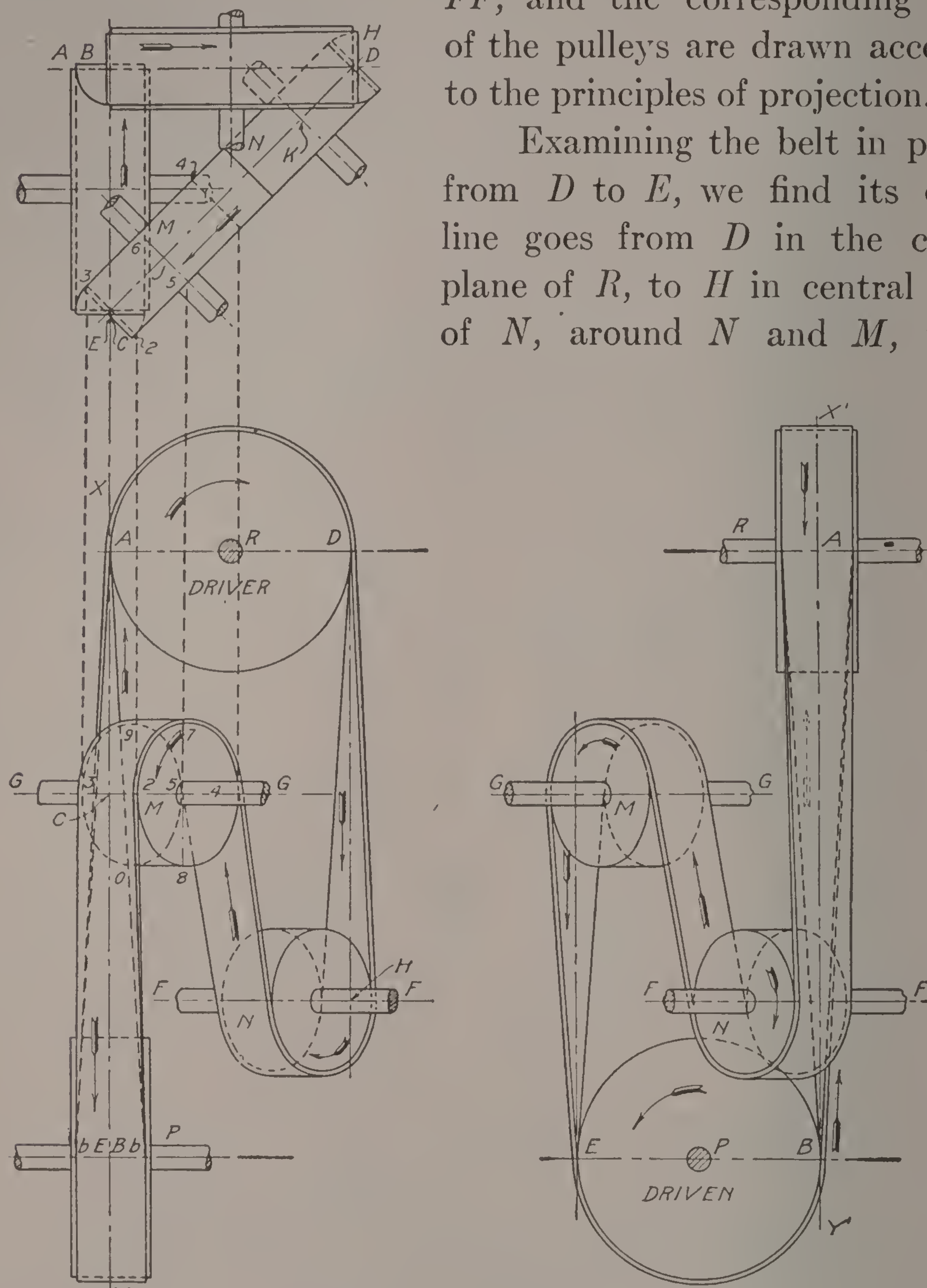


Fig. 101. Reversible Quarter-Twist—Two-Guide Pulleys

Examining the belt in passing from *D* to *E*, we find its center line goes from *D* in the central plane of *R*, to *H* in central plane of *N*, around *N* and *M*, which have one common central plane, arriving at *C*, a point in the trace of the central planes of *M* and *P*, and from leaving point *C* to receiving point *E*. It will be noted that the center line of belt connecting both leaving and receiving points is always in the central planes of both pulleys, and, therefore, the direction of motion may be reversed at will. If the belt be followed around the pul-

leys, we find both sides of the belt come, successively, in contact with the pulleys. Therefore, the belt must be given a single twist before uniting the ends together.

It is usually desirable to have only one side the working side; but if such were the case in this arrangement of pulleys, it would bring a sharp twist in the belt, between M and N, which might be a greater objection.

*One Guide-Pulley.** Fig. 102 shows the arrangement of the pulleys for the belt to run in either direction, using only one guide-pulley. The ordinary direction of rotation is that shown by the arrows. The upper pulley is the driver, and, as in the case where two guide-pulleys are used, the tight part of the belt goes directly from one main pulley to the other, the slack part of the belt returning over the guide-pulley. The shaft of the guide-pulley must be set at an angle with both main shafts in order to guide the belt properly. The method of locating the main pulleys is exactly the same as in the case where the two guide-pulleys are used, so that the explanation given for that case will apply here, and all we need to consider in this case is the location and drawing of the guide-pulley.

We shall first consider the two elevations. The plumb line XY, as well as being the center line of the tight part of the belt, is the line of intersection of the central planes of the two main pulleys. Choose a point in the line XY, which may be anywhere along the line, depending on how far the guide-pulley is to be from one or the other of the main shafts, but preferably about half-way between them. The point is marked M^h in the left-hand elevation, and M^v in the right-hand elevation. From M^h draw a line tangent to the upper pulley at D^h, and from M^{v}_{y} draw a tangent to the lower pulley at E^v. The other projection of the line M^hD^h will be M^vD^v, coinciding with XY in the right-hand elevation; and the other projection of M^vE^v will be M^hE^h, coinciding with XY in the left-hand elevation. We now have two lines, MD and ME (shown respectively by their two projections, M^vD^v—M^hD^h and M^vE^v—M^hE^h), which determine the plane of the guide-pulley and which are practically the center lines of that part of the belt which passes over the guide-pulley, and our problem is one of projections. The problem is to

*This section is optional.

find on the drawing paper the traces of the plane which contains the two lines, which is the central plane of the guide-pulley, and revolve

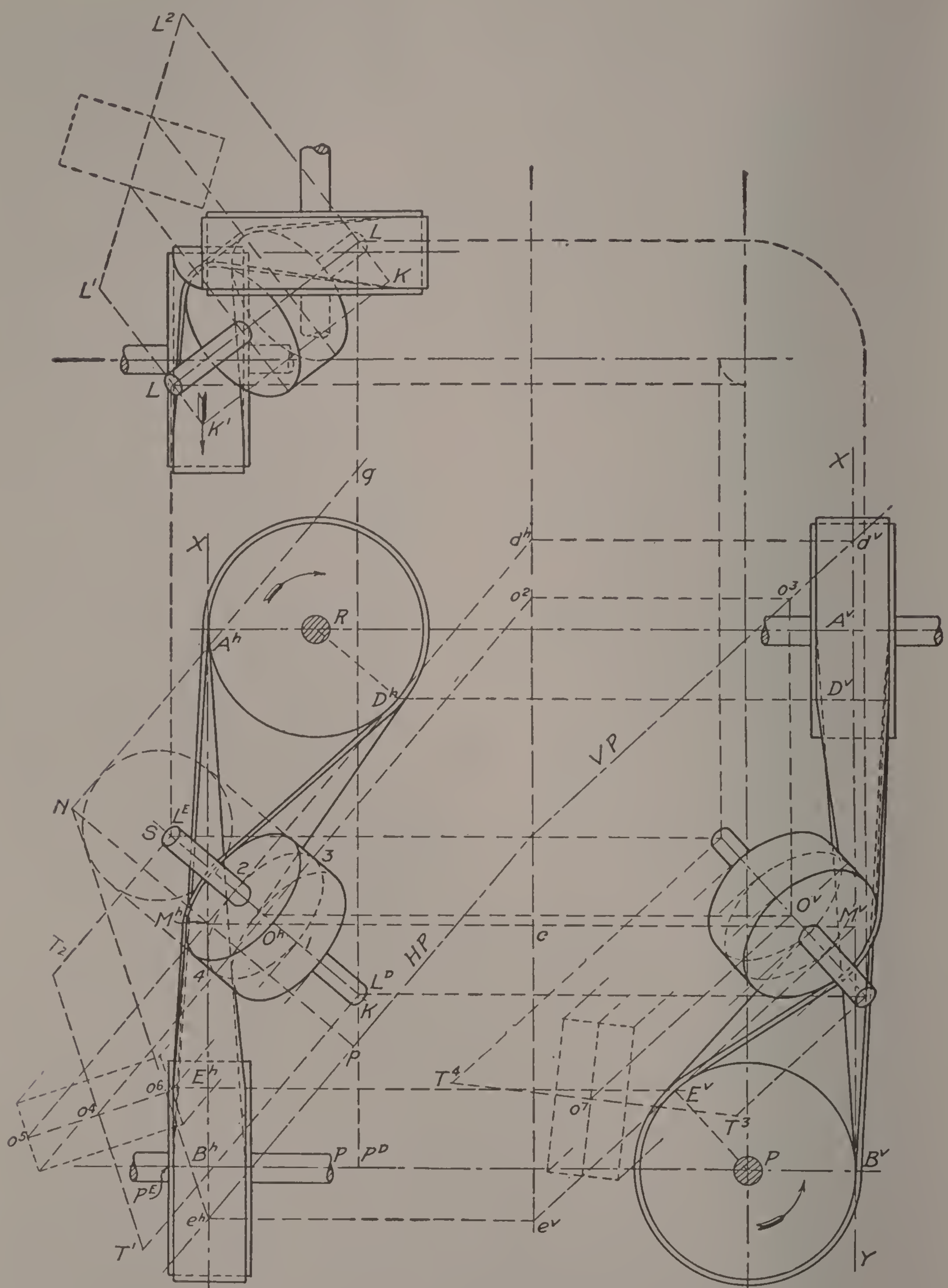


Fig. 102. Reversible Quarter-Twist—One Guide Pulley

this plane about one of its traces until it is parallel to the plane of the paper, so that the true angle between the lines will be shown;

then draw the guide-pulley tangent to the lines in their revolved position, and revolve the lines back to their former position, revolving the guide-pulley back at the same time. To carry out this construction, proceed as follows: Draw a ground line anywhere between the two elevations, parallel to XY; and, for the time being, consider one of the elevations as a horizontal projection and the other as a vertical projection, remembering that our drawing is made as if projected on two planes located as in Fig. 2, Machine Drawing, Part I, or, as it is commonly expressed, "in the third quadrant". We shall treat the left-hand elevation as if it were the horizontal projection, and the right-hand elevation as if it were the vertical projection. Extend line M^hD^h until it meets the ground line at d^h; and at d^h draw a perpendicular to the ground line, meeting XY (which is the same as M^vD^v extended) at d^v. Through d^v draw a line parallel to M^vE^v; and this line, which is marked VP, is the vertical trace of the plane which contains the lines MD and ME. In like manner find the horizontal trace by extending M^vE^v to meet the ground line at e^v, erecting a perpendicular at e^v to meet M^hE^h at e^h, and drawing HP through e^h parallel to M^hD^h. If the work is correctly done, HP, VP, and the ground line will intersect in a common point. Now through M^h draw a line perpendicular to HP, meeting HP at p. Construct the right triangle tm^hP (Fig. 103), making m^hP equal to M^hp on Fig. 102, and making m^ht equal to the perpendicular distance of M^v from the ground line in Fig. 102 (that is, equal to cM^v). Then take the distance Pt (Fig. 103) and lay it off on the line pM^h (Fig. 102) from p, thus obtaining point N. Join N and e^h, and through N draw Ng parallel to M^hD^h. The lines Ne^h and Ng are the projections on the horizontal plane of lines ME and MD, respectively, when the plane P, which contains these two lines, is revolved so that it is parallel to the horizontal plane. Therefore the angle gNe^h is the true size of the angle between lines ME and MD. Now, with a radius equal to the radius of the guide-pulley which is to be used, draw a circle which shall be tangent to the lines Ne^h and Ng. This circle is the central circle of the guide-pulley revolved parallel to the horizontal plane, and its center S is the revolved position of the center point of the guide-pulley, and, of course, lies in the plane P. To revolve the central circle of the guide-pulley back so as to get its two projections when it is in the position

which it actually occupies with relation to the two main pulleys, we shall first revolve the point S back to O^h. To do this, draw SK perpendicular to HP. Then in Fig. 103, lay off from P along the line Pt the distance PV, equal to SK in Fig. 102. Care must be taken to lay off this distance from P rather than from t; and in order to remember from which point to measure, the student can bear in mind that distances measured along the hypotenuse from P (Fig. 103) represent distances measured from HP (Fig. 102).

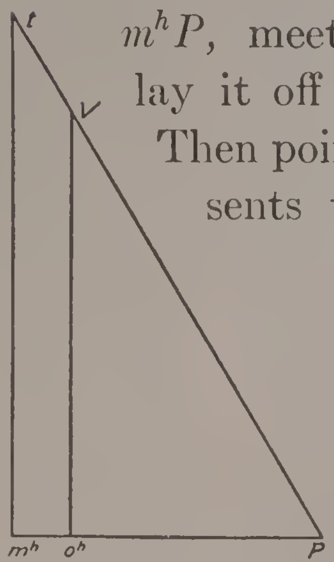


Fig. 103. Construction Diagram for Fig. 102

Having thus found point V, draw a line perpendicular to m^hP, meeting it in o^h; take distance o^hP in the dividers, and lay it off from K along KS (Fig. 102), thus getting O^h. Then point O^h will be the center of the ellipse which represents the center circle of the guide-pulley in its actual position. Point *2*, where KS cuts M^hD^h, will be one end of the the minor axis, and point *1*, found by laying off O^h1 equal to O^h2, will be the other end of the minor axis. The major axis is found by drawing a line through O^h parallel to M^hD^h, and laying off along this line from O^h the distances O^h3 and O^h4, each equal to the radius of the guide-pulley. Having now found the two axes of the center ellipse, it can be drawn by any geometric method for constructing an ellipse.

We shall next find O^v by prolonging the major axis of the ellipse just found until it meets the ground line at o^2, then erecting a perpendicular to the ground line at o^2 to meet VP at o^3, drawing a line through o^3, parallel to the ground line, and from O^h drawing a line perpendicular to the ground line which will meet the parallel through o^3 at O^v. This point will be the vertical projection of the center of the middle circle of the guide-pulley. The ellipse, which is the vertical projection of this middle circle, is found from O^v in a way exactly similar to that in which the ellipse for the horizontal projection was found from O^h.

The next step is to draw the guide-pulley and its shaft, and to do this we shall revolve the central ellipse over in each view in such a way that we shall have it projected as a line. We shall take the horizontal projection first. Extend the major axis of the ellipse from O^h to o^4, making O^ho^4 equal to the perpendicular distance of

O^v from the ground line. Draw $O^6 1$ through point 1 parallel to $O^h o^4$. With o^4 as a center, and with a radius equal to the radius of the guide-pulley, cut $o^6 1$ at o^6, and cut $D^h M^h$ extended at o^5. Points o^6, o^4, and o^5 will be in a straight line, and the line joining them will be the edge view of the central circle of the guide-pulley. About this line $o^6\ o^5$ draw a rectangle as shown, the width of the rectangle being made equal to the width of the face of the guide-pulley. Through o^4 draw a line perpendicular to $o^6 o^5$, which will be the revolved position of the center line of the guide-pulley shaft. The method of revolving back to get the axes of the ellipses, which are the projections of the edges of the pulley in its actual position, and to get the projection of the shaft, will be clear from a careful study of the figure.

The vertical projection of the guide-pulley is found by revolving over in exactly the same way, the distance $O^v o^7$ being equal to the perpendicular distance of O^h from the ground line. It is well to assume a definite length for the shaft, whether this be the actual length which the shaft would have or not. The length assumed in the figure is $T^1 T^2$ (same as $T^3 T^4$), and half of this is laid off each side of o^4 in the revolved horizontal projection.

This completes the two elevations of the guide-pulley. The plan is drawn as follows: Find the projection LL of the two ends of the shaft as shown by the construction lines; then revolve over by drawing line KK^1 at any convenient place parallel to LL, drawing perpendiculars through the points LL, meeting the parallel line at K and K^1, and laying off on these perpendiculars the distances $K^1 L^1$ and KL^2, equal respectively to $L^D P^D$ and $L^E P^E$ in the elevation. The line $L^1 L^2$, joining the points L^1 and L^2 thus found, is the revolved position of the shaft, and should be equal in length to $T^1 T^2$ and $T^3 T^4$ in the elevations.

We can now draw the rectangle which represents the revolved position of the guide-pulley at the middle of the line $L^1 L^2$, and find the ellipses from this rectangle in the same way as we found the ellipses from the rectangle in the other two views.

The belt is drawn in accordance with the same kind of reasoning as was used in determining the way the belt would look in the other kinds of quarter-twist belts which we have studied.

Belts Connecting Shafts in Same Plane But Not Parallel. It very often happens that a belt must connect two shafts which are on the same level, but which are not parallel. The connection can be made, whatever the angle between the shafts, by the use of two guide-pulleys. If the two main-shaft pulleys are of the same diameter, the belt may be made to run in either direction by putting both guide-pulleys—or mule pulleys, as they are often called—on the same shaft, which will be perpendicular to the plane containing the axes of the main shafts. That is, if the main shafts are horizontal, the shaft for the guide-pulleys will be vertical. If the main pulleys are of different diameters, the guide-pulleys may still be placed on the same vertical shaft, but in this case the belt can run in only one direction. If the belt is to run in either direction, the guide-pulleys are placed on separate shafts, which are usually adjustable in position, so that they may be tipped at the proper angle to receive and deliver the belt.

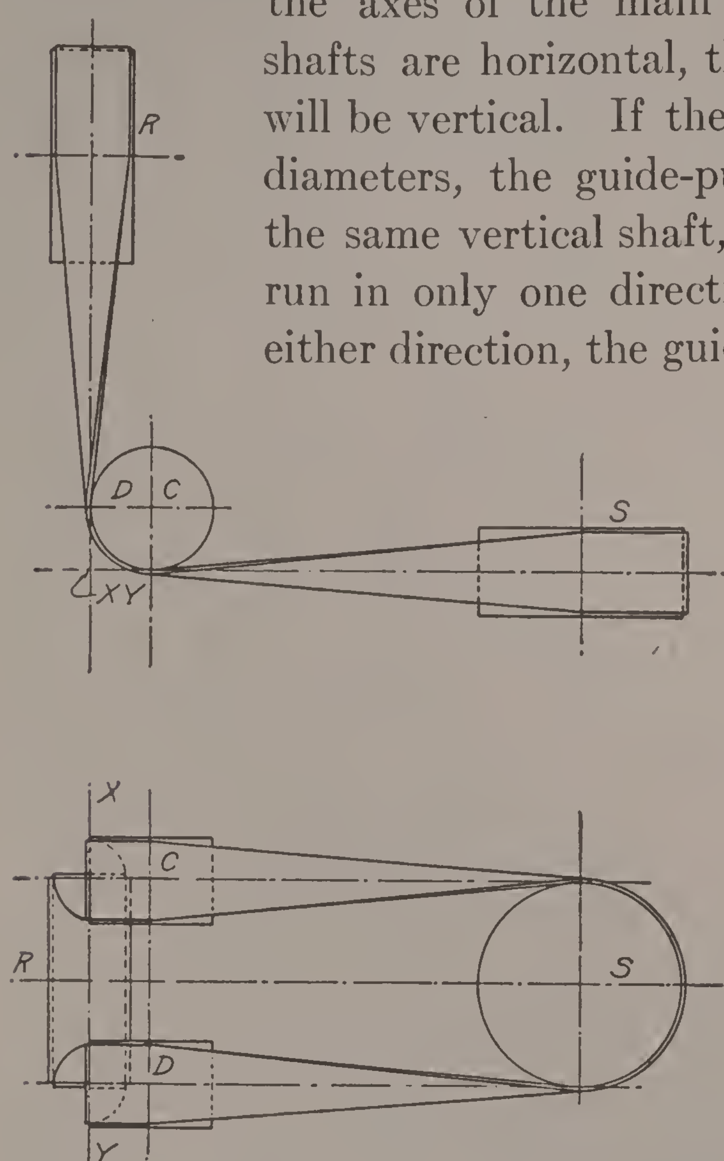


Fig. 104. Belt Drive for Same Sized Pulleys, Shafts not Parallel but in Same Plane.

We shall first take the case where the two main pulleys are of the same size. Fig. 104 shows the arrangement, the upper view being the plan, and the lower view, the elevation. R and S are the two main pulleys, and C and D are the two guide-pulleys. The line XY is the line of intersection of the planes of the main pulleys. The location of the guide-pulleys is sufficiently clear from the drawing, without further explanation.

Fig. 105 shows the arrangement when the main pulleys are of different diameters. Here the pulleys can turn only in the direction shown by the arrows; for if the direction were reversed, the belt would leave the pulleys. The pulleys in plan appear the same as

in Fig. 104. In the elevation, the upper guide-pulley, which receives the belt from S, has its central plane tangent to the pulley S at the point where the belt leaves S, as shown by the line A^vB^v. The lower guide-pulley, which receives the belt from R, has its center plane tangent to R, as shown by C^vD^v. If the pulleys were to turn in the opposite direction, the upper guide-pulley would have its plane tangent to R, and the lower one, its plane tangent to S.

Cone Pulleys. It is often necessary to provide a range of speed variation in a shaft belted from a line shaft running at a constant rate. A familiar case of this kind is the ordinary lathe spindle. This may be done by shifting the belt from end to end of either a pair of cones or conoids, Fig. 106, depending on whether the belt is crossed or open. To work satisfactorily, a shipper must be located at each cone or conoid to guide the belt; otherwise it may climb. As these shippers give trouble and wear the belt, and the belt itself is unequally stretched, it is usual to approximate the conoids by stepped cones, or cone pulleys. In order to have the belt equally tight for each pair of steps, the diameters of the steps must be so proportioned that the length of belt remains constant.

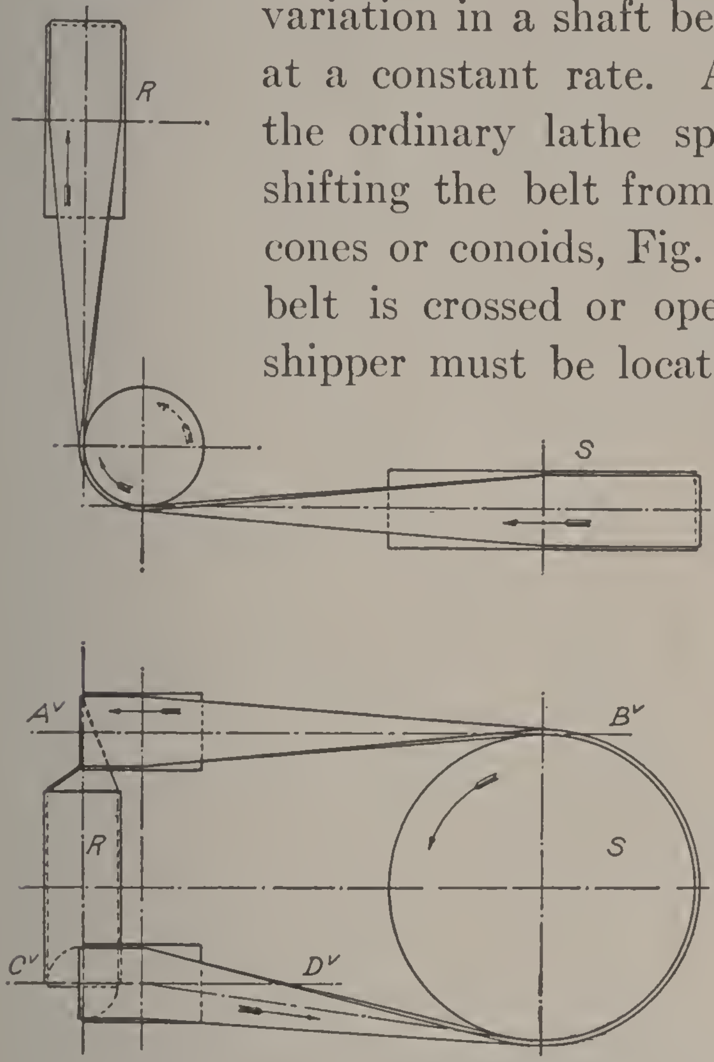


Fig. 105. Belt Drive with Main Pulleys of Different Diameters

It can be shown, geometrically, that for a crossed belt this condition is obtained when the sum of the diameters of each pair of steps is constant. In Fig. 106, a three-step cone with crossed belt is shown; and, adding together the diameters of the pair of steps connected by the belt, we have $11+6=17$ for the constant of this cone pulley.

For an open belt, an extended calculation is necessary for diameters giving a constant belt length, and a simple graphic method for laying out the cones has been published by Mr. C. A.

Smith in "Transactions of the American Society of Mechanical Engineers" (Vol. 10, p. 269). Here the distance between shafts and diameters for one cone pulley is assumed, or is known from the conditions of the drive.

In Fig. 107, lay off AB equal to the distance between centers of shafts; and with these points as centers, draw circles C and D equal, respectively, to the maximum and minimum diameters of the

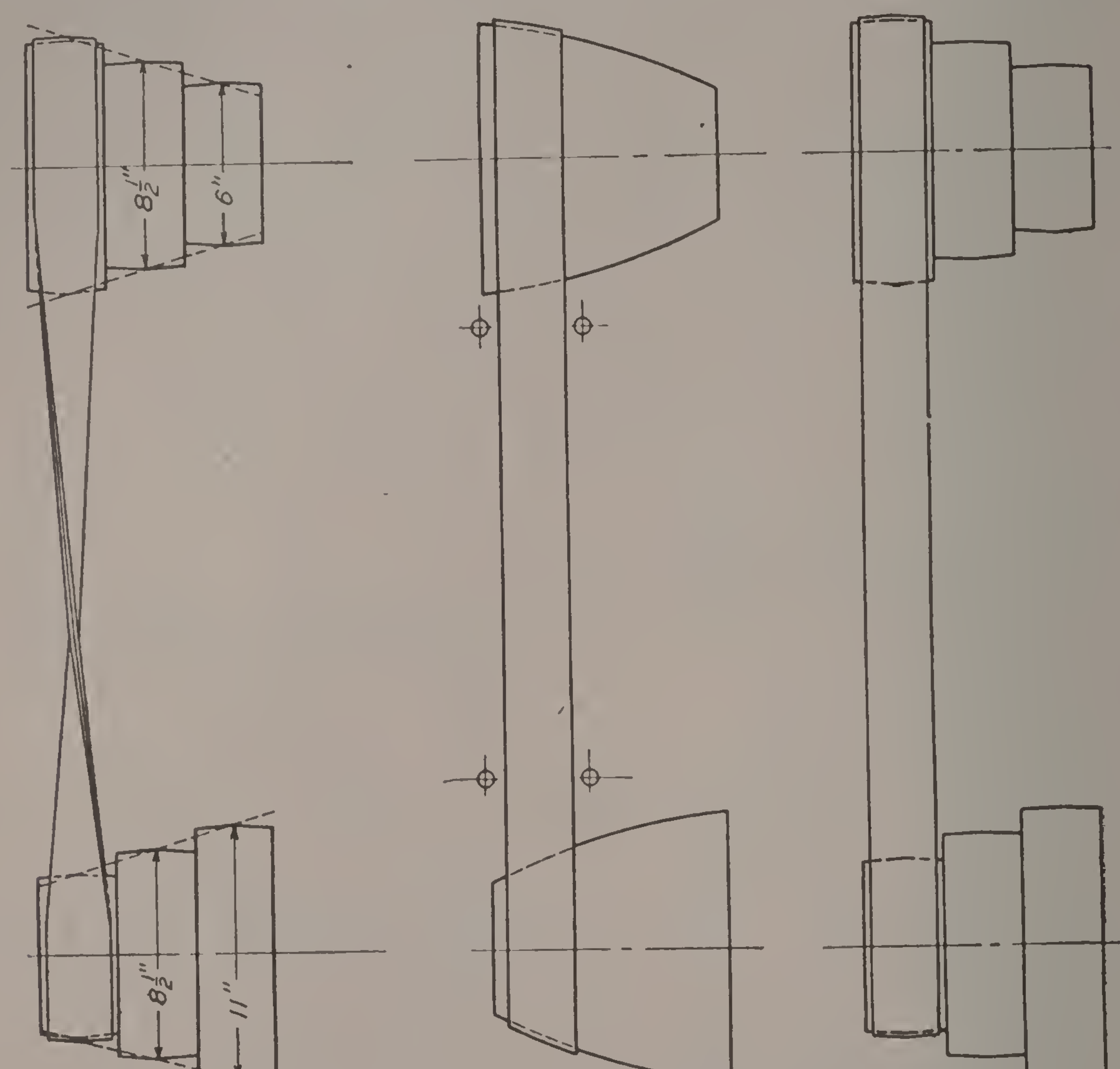


Fig. 106. Cone Pulleys for Spindle and Countershaft

given cone pulleys. Draw the belt line EF. From a point G, half-way between A and B, erect GH perpendicular to AB, and make it equal to 3.1416 AB (for the sake of space, it is not drawn to this scale in the cut). With H as a center, draw a circle tangent to EF; then the belt line of any other pair of pulleys must be tangent to this latter circle.

Assume D_1 the diameter of one of the pulleys, and draw a common tangent to circles D_1 and H, producing it past the center B. From B draw a perpendicular BF_1 to the common tangent; and with BF_1 as a radius, draw in the circle C_1, which will give

the pulley required to work with D_1, and having approximately the same length of belt as on pulleys D and C. Continue the process until the required number of steps have been obtained. It must be noted that the limit for which this construction can be used is reached when the belt angle K is equal to 18°. When the angle K is between 18° and 30°, proceed as follows:

Locate another point J on the line GH so that the distance HJ is equal to $.298AB$; draw a tangent to circle H, making an angle of 18° with the line of centers AB, and from point J draw an arc tangent to this tangent. Make all belt lines which are greater than 18° tangent to this arc.

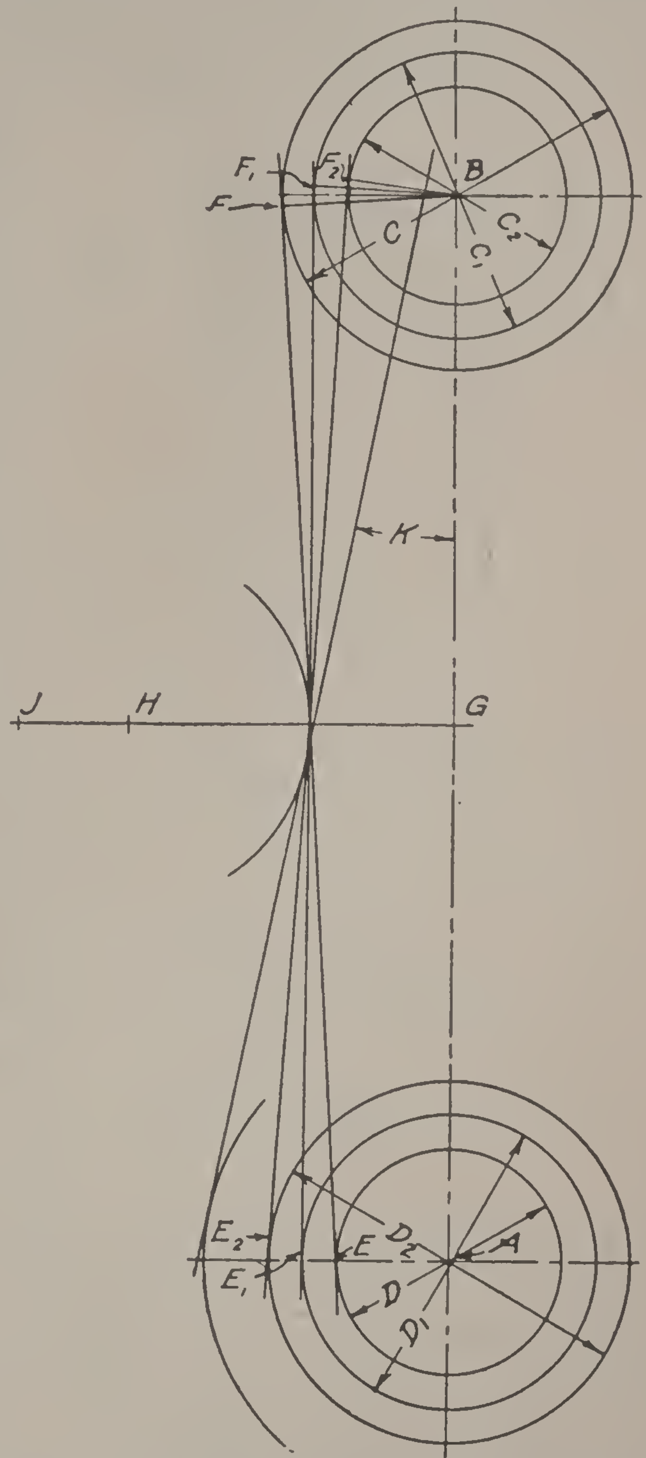


Fig. 107. Diagrammatic Layout for Cone Pulleys

Belt Holes. Very often a belt has to pass through a floor or partition. The holes through which the belt runs should be large enough to be sure that the belt shall never strike the sides, but it is desirable that they should be no larger than is necessary to accomplish that result. Accordingly, the holes should be laid out so that they may be cut in the right place and at the proper angle. Figs. 108 to 110 show the method of locating the position of the floor holes for the various kinds of belts, the top only of the floor being shown.

In Fig. 108 we have a common open belt. The circles representing the pulleys are drawn, and the belt drawn around them. A short pitch line should be also drawn in each part of the belt where it passes through the floor. These parts of the pitch line are simply lines parallel to, and halfway between, the lines which repre-

sent the outer and inner faces of the belt. Next draw the two rectangles which represent the plan view of the pulleys, and draw through them the center line *RS*. From the points *E* and *H*, where the pitch line intersects the line representing the top of the floor, draw perpendiculars to *RS*, meeting it in points *F* and *G*. *F* and *G* are the center points of the rectangles *1 2 3 4* and *5 6 7 8*, which form the outline of the belt holes on the surface of the floor. The long dimension of the rectangles will be parallel to the shafts on which the pulleys are located. After the belt holes are so found, the distances of their center lines to the right or left of the lines *T* and *X*, respectively (which are the center lines of the shafts), can be measured on the drawing, and the workman can mark them out on the floor by plumbing down (or up) from the shafts, getting the lines *T* and *X* on the floor directly under or over the center of the shafts, and thus locating on the floor the points *F* and *G*, and consequently the belt holes, from the dimensions taken from the drawing.

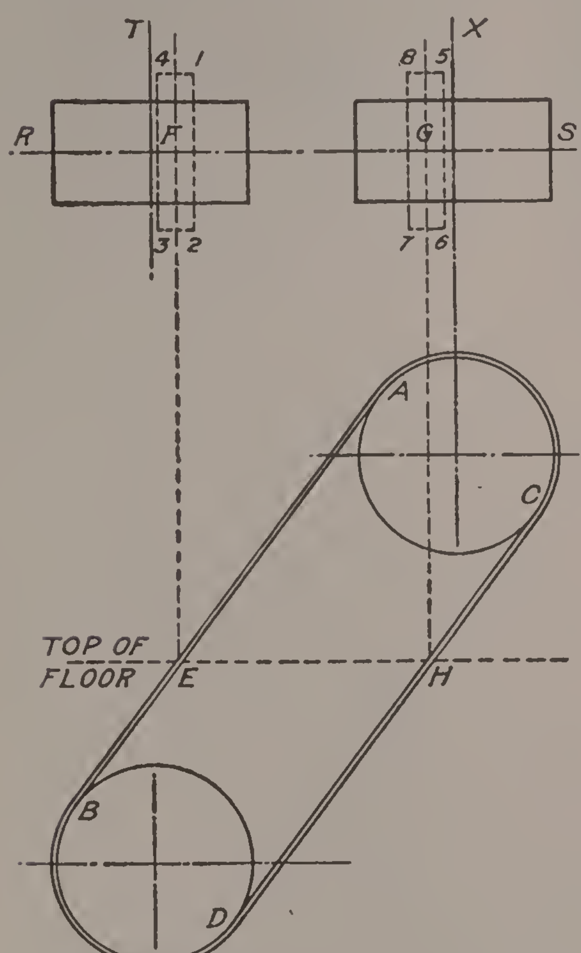


Fig. 108. Diagram Showing Method of Locating Belt Holes

Fig. 109 shows how to draw the holes for a crossed belt. Draw the two views of the pulleys and the center lines *AC* and *DB* of the belt in the elevation; also the center line *RS* in the plan. It is well, also, to draw the belt complete in the elevation, as it makes it easier to determine which way the belt holes will slant. From points *E* and *H*, where the center lines of the belt intersect the floor line, draw *EL* and *HK* perpendicular to *RS*, and meeting *RS* in *F* and *G*. The points *F* and *G* are the center points of the belt holes, and it only remains to determine the angles which the center lines of the holes make with *T* and *X*, respectively. These will be the same as the angles made with *HK* and *EL*. When the belt is leaving the pulley at *A*, a line drawn perpendicularly across to its inner face would occupy the position indicated by the dotted line *aa′* in plan;

and the belt, in passing from A to C, twists through an angle of 180°, and the line which was at aa' will occupy the position cc'. Therefore, when the belt has passed from A to H, it will have twisted

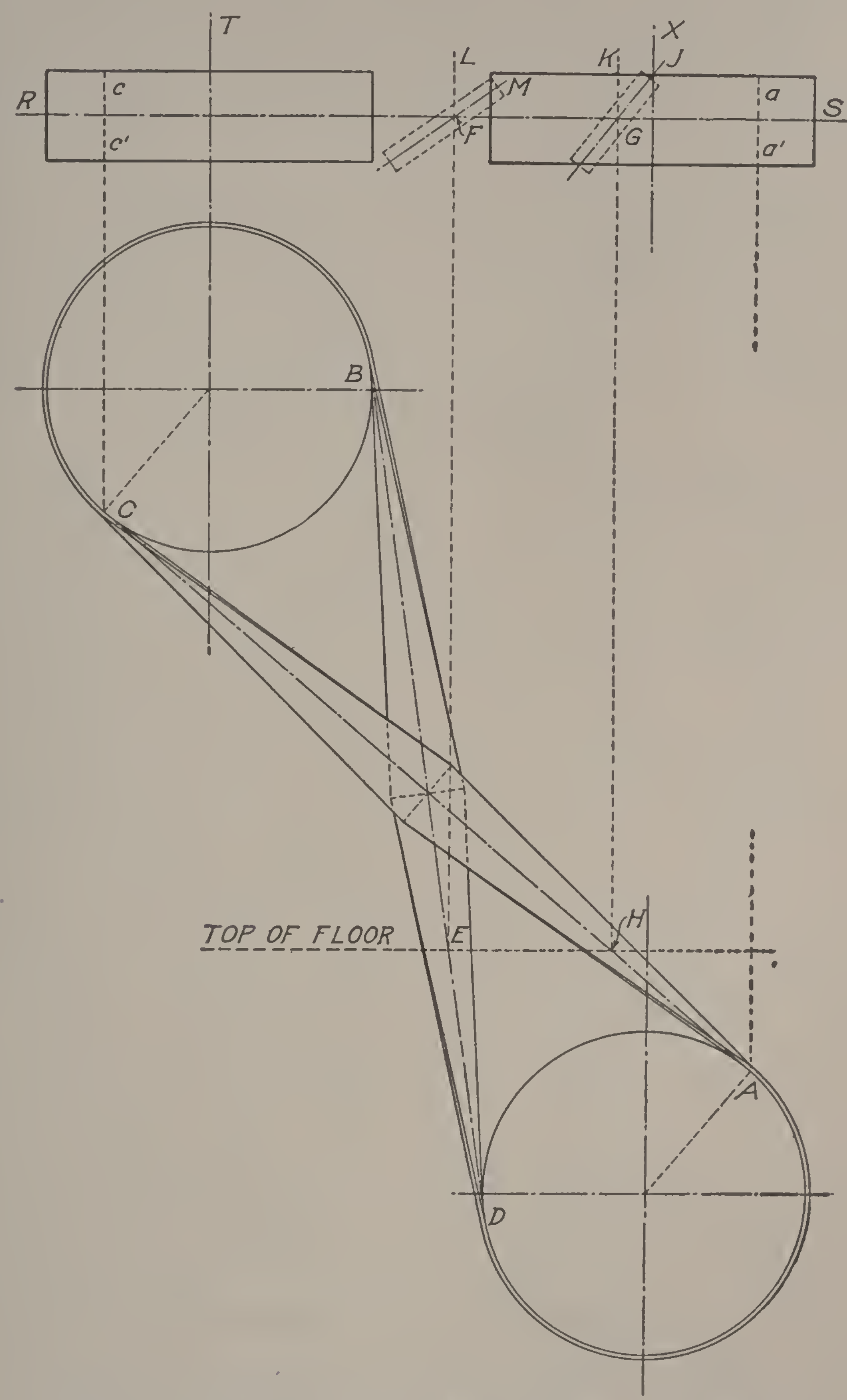


Fig. 109. Diagram Showing Location of Holes for Crossed Belt

through an angle which will bear the same relation to 180° that the distance AH bears to the distance AC. That is, if $AH = \frac{1}{4}$ of AC, the angle JGK is $\frac{1}{4}$ of 180°, or 45°. Whether the angle JGK shall be laid off to the right or to the left of line HK, must be reasoned out by considering which way the belt twists in passing A to C. The angle of the other belt hole (LFM) is determined in the same way.

Fig. 110 shows the method of finding the belt holes of a plain quarter-twist belt, similar to Fig. 98. The centers *G* and *F* in plan are found by projecting from the elevation, as shown by the construction lines. The angle which the center line of hole at *G* makes with the center line of the shaft, is found by dividing 90° in the ratio of the distances *P* and *N*. The angle of the center line of the belt

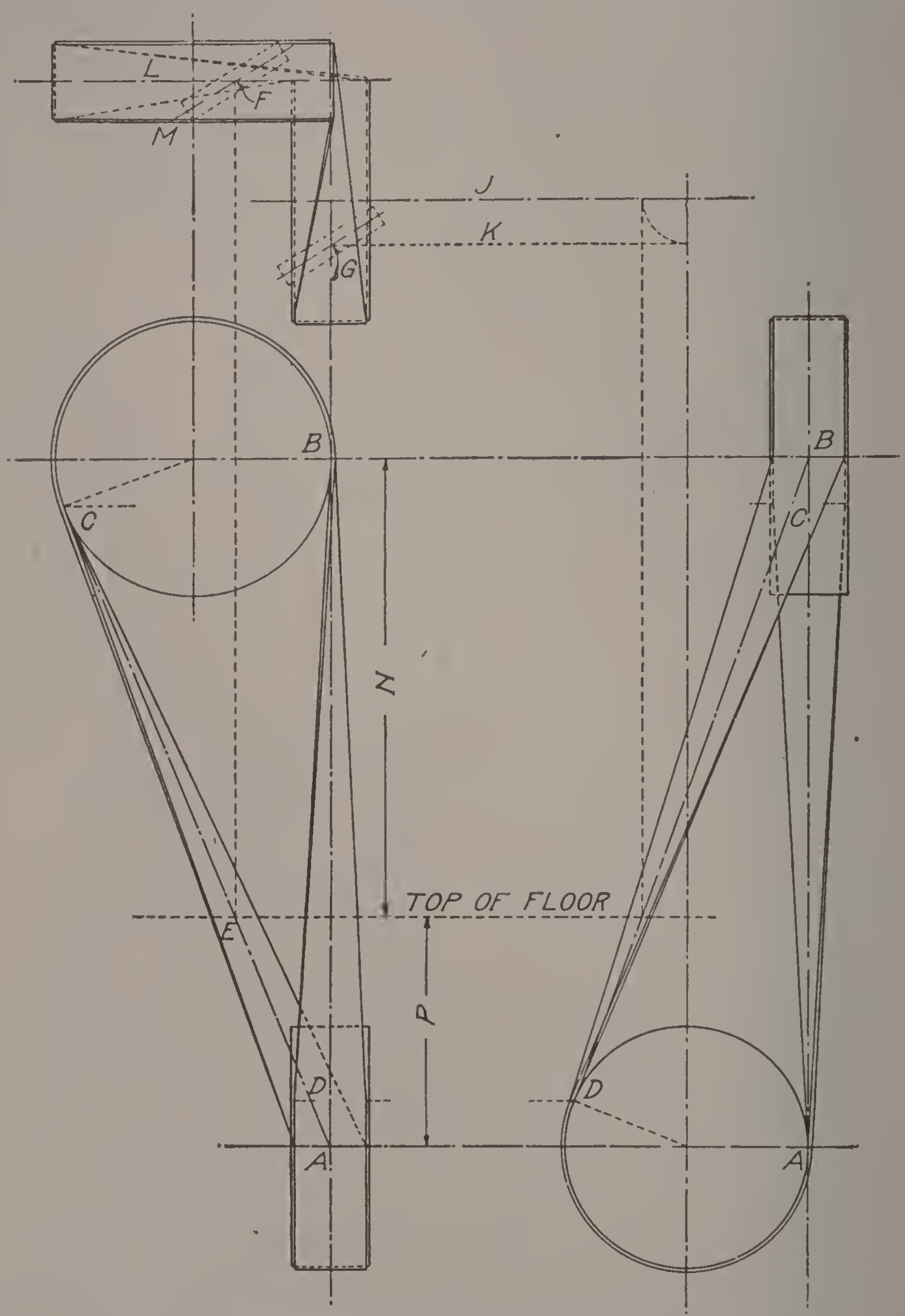


Fig. 110. Locating Belt Holes for Quarter-Twist Drive

hole at *F* with the center line of the shaft, is found in a similar manner, by dividing 90° in the ratio of the distance *AE* to *EC*. It is usually sufficiently accurate, however, after having found the angle at *G*, to draw the center line of the other hole parallel to it.

General Practice. *Working Conditions.* A belt drive is working under the most favorable conditions when, though not pulled up excessively, the belt "hugs" the pulleys tightly and wraps a large proportion of their circumference.

Slipping. In the case of two pulleys of different diameters, made of the same material, connected by a belt, the belt will slip first on the smaller pulley, partly because the wrap of the belt is less upon that one, partly because the belt does not "hug" so tightly, owing to the smaller radius of curvature to which the belt must be bent. Sometimes the smaller pulley is lagged with rubber or leather so as to give it increased grip on the belt, thus making up for the tendency to slip, due to its small diameter.

Location of Slack in Belt. On an inclined or horizontal drive the slack side should be on top, and the tight or pulling side underneath, as the weight and slackness of the belt will act together to cause it to sag and increase the wrap. It is a well known fact that the greater the arc of contact, the greater the driving force which may be obtained from the belt.

Vertical Drives. Vertical drives should be avoided as much as possible, as here the weight of the belt is always tending to decrease the "hug" on the lower pulley.

Diameters of Pulleys. Increasing the diameter of pulleys, the same linear speed of belt being maintained, does not increase the power transmitted, except by permitting the belt to "hug" the pulleys more tightly; and the larger the pulleys, the better this condition becomes, providing we do not exceed a certain economic speed for the belt. Flexible link belting, made of small leather links joined together by steel wire, gives excellent results, especially when used on horizontal drives, but it is rather expensive to install. A pulley rim perforated with small holes, to prevent any air cushion beneath the belt, is another means of increasing the "hug."

Belt Tighteners. Belt-adjusting devices are often provided for changing the distances between the pulleys, thus enabling the proper tightness to be always maintained. Motor and dynamo bases are provided with slides and set screws for such adjustment.

A tightener pulley is often used to increase the wrap of the belt or maintain the proper tightness. This is an idler pulley, which is weighted, or adjusted by screws against the belt. While such a

pulley is a very ready and simple means of accomplishing the purpose, yet it should be remembered that the shaft carrying it is subjected to heavy pressure in its bearings, due to the belt tension; and the friction of the drive is considerably increased thereby. Tightener pulleys are used only when specific conditions prevent the results from being otherwise secured.

Stiffness of Belt. It is generally preferable to use belts of two or more thicknesses for the sake of side stiffness, and also in order that any local imperfections of the leather in one layer may be taken care of by the other. Where the belts are to be shifted laterally, stiffness is an important item. If too pliable a belt is used on cone pulleys, the edges are apt to curl up, and the belt tends to climb and chafe against the side of the step, twisting like a corkscrew, and sometimes jumping from one step to another.

Distance Between Pulley Centers. A good distance between the centers of shafting for ordinary belt drives is from 20 to 25 feet. With greater distances, the belt is apt to flop and run in waves; while at a less distance, the necessary tightness of the belt results in undue stretching. In crossed belts, the above distances should be especially adhered to; for, with a wide, stiff belt and a short distance between centers, there is an excessive amount of rubbing on the sides of the belt, as well as strain caused by the twisting.

Crossing and Quarter-Twisting. It is well to use as few crossed and quarter-twist belts as conditions will permit. In quarter-twist belts, the side angle, where the belt leaves the pulley, should be kept under 25°, as considerable power is lost in side slipping. For the least distance between the shafts a safe value is obtained if the distance is made not less than $2\frac{1}{2}$ times the diameter of the larger pulley. A narrow belt gives better results than a wide one, on twisted belting.

GEARS

General Theory of Gears. Fig. 111 represents a pair of disks fastened to shafts A and B, respectively, and touching at the point P. If these disks be pressed tightly against each other, sufficient friction will be produced between them to cause one to drive the other. The number of revolutions B would make in a given time, would be to the number of revolutions made by A as AP is to BP; or,

$$\frac{\text{Revolutions } B}{\text{Revolutions } A} = \frac{AP}{BP}$$

Such friction disks will transmit but very little power without slipping; and even when required to transmit small power, cannot be depended upon to drive positively, as the least wear or loss of adjustment is liable to make them slip. Hence teeth are provided on each disk, such that they will lock together and make it sure that when one disk is rotated the other must move also, without regard to whether the disks are pressed tightly together or not. In fact, it is desirable that this side pressure be avoided, in order to prevent excessive friction in the bearings of shafts A and B.

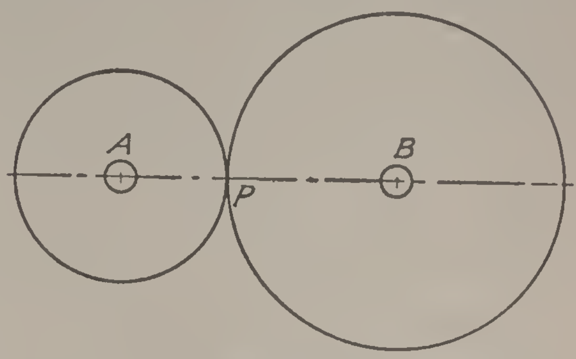


Fig. 111. Diagram of Simple Gear Principle

Any shapes whatsoever of teeth would answer, provided they interlocked, so far as positive driving is concerned. But in order that the *revolutions of the shafts shall always be inversely as the contact radii*, or

$$\frac{\text{Revolutions } B}{\text{Revolutions } A} = \frac{AP}{BP}$$

it can be shown by geometry that the *common normal drawn through the point of contact of any pair of teeth must always pass through the point P.*

A pair of gears, therefore, may be considered to be based on two disks, touching as in Fig. 111, and provided with teeth such that these two conditions are fulfilled:

1. Positive driving at all times.
2. The common normal through the point of contact of any pair of teeth always passing through the pitch point.

Pitch Circles. The circles corresponding to the disks are known as pitch circles, their diameters pitch diameters, and the point of contact P the pitch point (see Fig. 112). The distance, measured radially, from the pitch circle to the top of the tooth is called the addendum; and the circle through the top of the tooth, the addendum circle. The distance, measured radially, from the pitch circle to the beginning of the fillet at the bottom of the tooth, is called the dedendum; and the circle through this point the dedendum circle. In order that the top of the tooth on one gear shall not strike the surface between the bottoms of the teeth on the other, a further

distance is allowed between the dedendum circle and the root circle, known as the clearance. The distance from the center of one tooth to the center of the next, measured on the pitch circle, is called the circular pitch, and is evidently equal to the circumference of the pitch circle divided by the number of teeth.

In order to run together, two gears must have the same circular pitch. The number of teeth in a pair of gears is proportional to the circumference of the pitch circles, and therefore to the pitch diameters, or pitch radii. The speeds of the shafts carrying the gears, being inversely proportional to the diameters of the pitch circles, are also inversely proportional to the numbers of teeth.

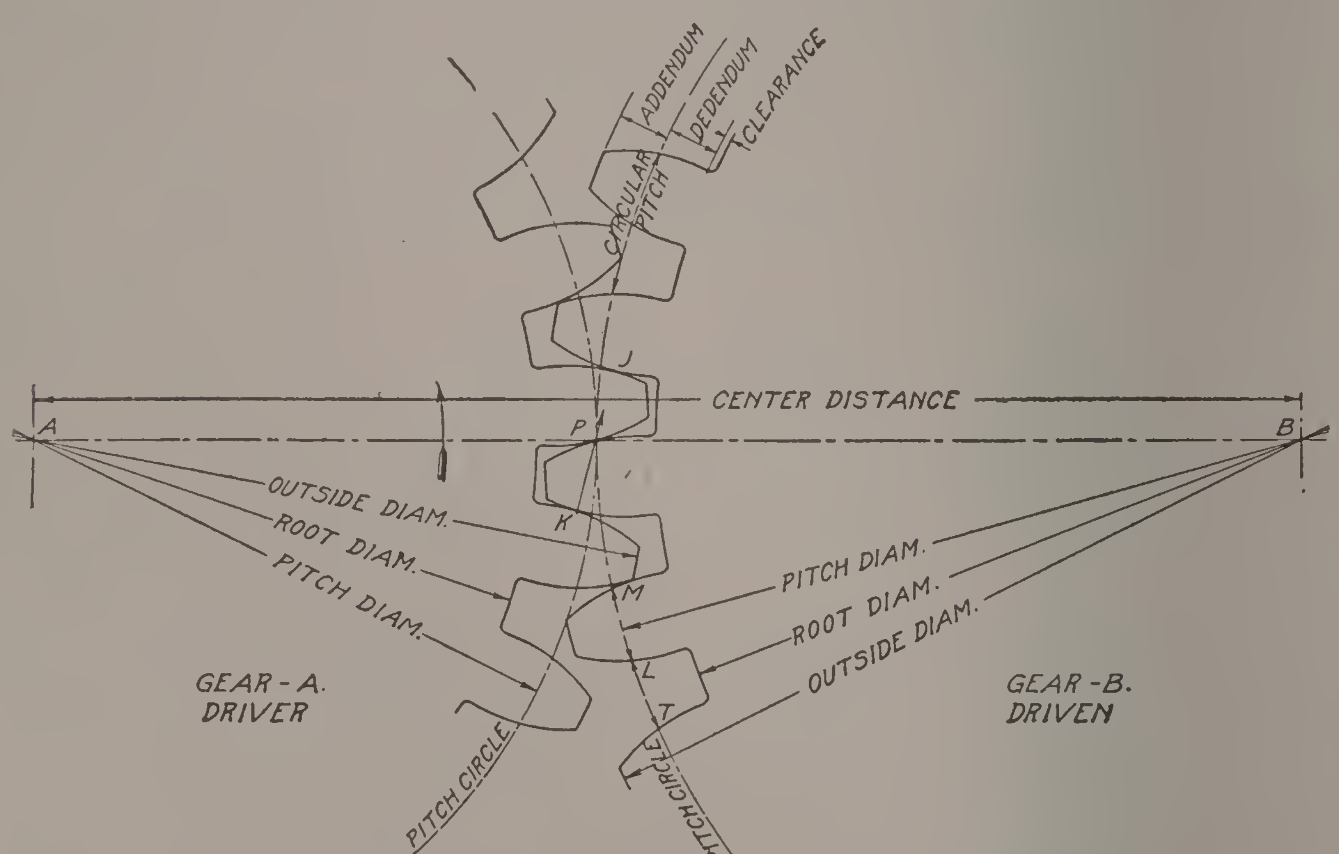


Fig. 112. Layout for Pair of Gears, Showing Construction Features

Circular and Diametral Pitches. Since the circular pitch is equal to the circumference of the pitch circle divided by the number of teeth, there is a fixed relation, for any given gear, between the pitch diameter and the number of teeth. This relation is known as diametral pitch. Diametral pitch is not a distance, like circular pitch, but is the number of teeth per inch of pitch diameter of the gear. For example, if the diameter of the pitch circle of a gear of 60 teeth were 20″, the number of teeth per inch of diameter would be $\frac{60}{20}=3$, and the gear would be described as a "60-tooth, 3 diametral-

pitch gear". The product of the circular pitch times the diametral pitch, is always equal to the constant, 3.1416; that is, if we have one kind of pitch, and wish to change to the other, we divide 3.1416 by the given pitch. For example, 4 diametral pitch is equal to $\frac{3.1416}{4}=.7854''$ circular pitch. Again, 2″ circular pitch is equal to $\frac{3.1416}{2}=1.57$ diametral pitch. Note carefully that diametral pitch is not "inches", but number of teeth per inch of diameter.

Diametral pitch is very convenient to use, as the calculation is simpler than with circular pitch, and the pitch diameters of the gears come in even figures, or in even fractions of the pitch. For machine-cut gears it is universal practice to use diametral pitch in the specification. For cast gears, where the teeth are fashioned by the pattern maker, it is common to use circular pitch.

The thickness of the tooth LM, Fig. 112, is practically the same as the space TL for machine-cut gears. For cast teeth, however, the tooth must be thinner than the space, to allow for the inaccuracies of the pattern and casting. This allowance measured on the pitch circle is called backlash.

Discussion of Terms. These terms are illustrated in Fig. 112; also the common normal KP to a pair of teeth in contact. Gear A, being the driver in the direction shown, a pair of teeth are in contact at point K. The curves of the teeth being of the correct shape, if a common tangent be drawn, and a perpendicular erected at the point of tangency K, it will pass through the pitch point P. Now, as the gears move in the direction of the arrows, the teeth slide upon each other, and the point of contact changes, coming closer and closer to point P, then passing through P, and, going on, reaches some point as J, which, in the present example, represents the second pair of teeth in contact. During all this motion of the teeth, the common normal at every point of contact will pass through the pitch point P, thus fulfilling the condition of uniform velocity.

Pressure Line. It will be remembered that the pressure line between two surfaces, as illustrated in the discussion of cams, is the common normal at the point of contact. Now, a pair of gear teeth is like a cam and its follower; and if we wish to find the direction of the pressure between them, we simply draw the common normal.

Hence, knowing that with the teeth of proper outline the common normal will pass through the pitch point, we merely find the point of contact of any pair of teeth and connect it by a straight line to the pitch point, thus giving the direction of pressure between the teeth at the given position.

CYCLOIDAL GEARS

Two kinds of curves fulfill the requirement for gear teeth, that the common normal shall pass through the pitch point. These are the cycloidal and involute curves. The latter curve, for many reasons, has almost entirely displaced the former. The cycloidal curve is useful in special cases, and is still adhered to by its few advocates, as having peculiar merit, even for standard work. The general and best standard practice, however, is unalterably committed to the involute system, and experience has shown the reasons therefor to be sound ones.

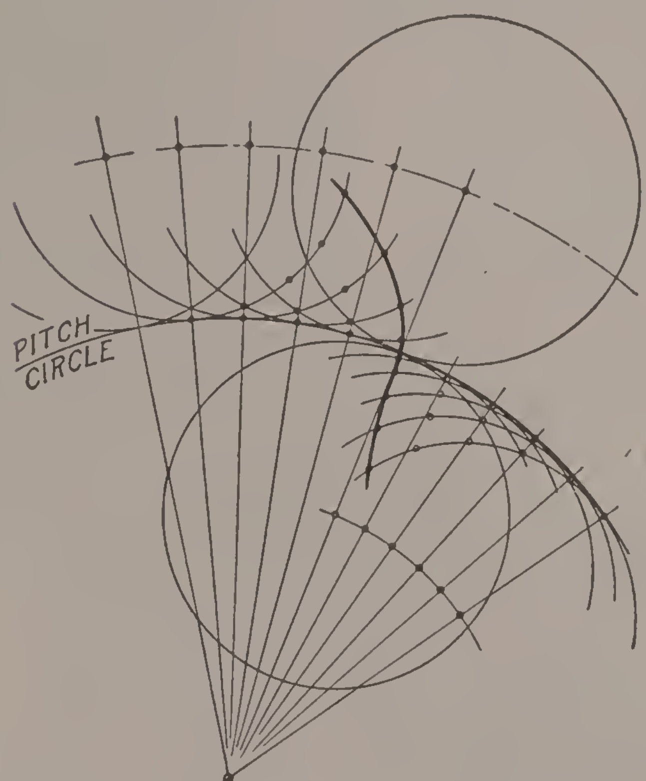


Fig. 113. Methods of Drawing Cycloidal Curves

Formation of Cycloidal Curves. The student can best approach the subject of the design of gear teeth through a study of the cycloidal system, the principles being capable of clearer illustration. Hence this system will be first presented.

The method of drawing the cycloidal curves by the use of rolling circles is illustrated in Fig. 113. The accurate curve, having been developed, may be transferred by the tracing-cloth method, as in cams, to each individual tooth; or arcs may be found by trial which approximate to the true curve; or a templet of stiff paper or cardboard may be made.

Design of Epicycloidal Gears. Fig. 114 shows a pair of epicycloidal gears designed to run together. The centers of the gears are at *B* and *A;* the pitch circles are shown in dot-and-dash, and are in contact at the pitch point *P*. The circle whose center is *C*,

shown dotted, by rolling on the inside of the pitch circle of the gear *B*, generates the hypocycloid *PE*, which forms the flanks of the teeth on gear *B;* and by rolling on the outside of pitch circle of gear *A*, generates the epicycloid *PF*, which forms the faces of the teeth on gear *A*. In like manner the circle whose center is *D*, by rolling on the inside of the pitch circle of gear *A*, generates the hypocycloid *PG*, which forms the flanks of the teeth on *A;* and by rolling on the outside of the pitch circle of *B*, generates the epicycloid *PH*, which forms the faces of the teeth on *B*. The circles *C* and *D* are called the describing circles. If the gear *B* is the driver and is turning in

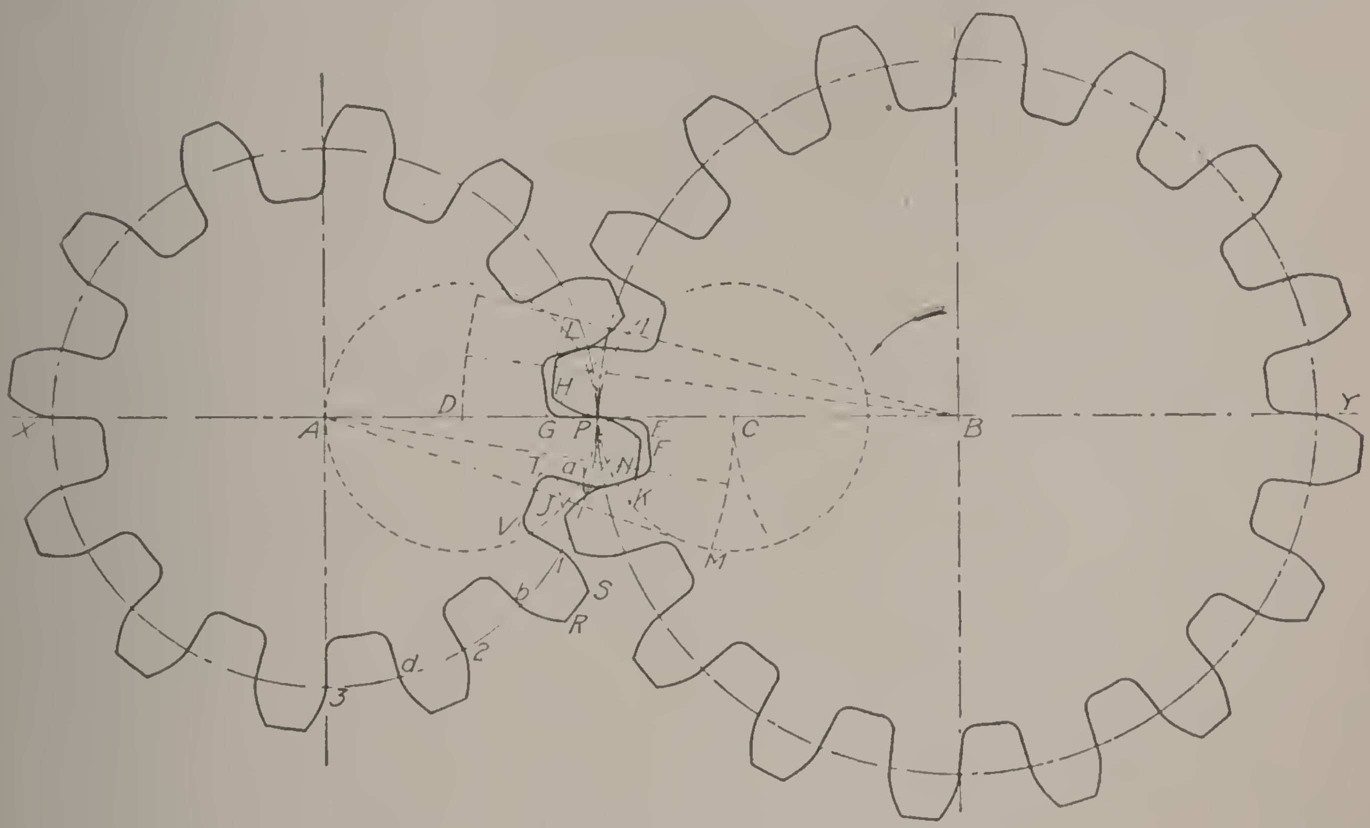


Fig. 114. Construction of Epicycloidal Gears

the direction shown by the arrow, the flanks of its teeth act on the faces of the teeth on *A* from the point where they first come in contact until the point of contact reaches the pitch point; and from the pitch point on until the contact ceases, the faces of the teeth on *B* act on the flanks of the teeth on *A*. In other words, the hypocycloidal part of the tooth curve on one gear is generated by the same describing circle that generates the epicycloidal part of the tooth on the other gear with which it is in contact. This must always hold true, in order to have the gears run properly. The arc *IP* of the describing circle *C*, together with the arc *JP* of the describing circle *D*, forms what is called the path of contact; that is, the point of contact between the teeth is always somewhere on the

line IPJ. If the gear A were the driver, the direction of rotation remaining the same, the path of contact would be LPK.

To design a pair of epicycloidal spur gears, we must have given the pitch (either diametral or circular), the diameters of the pitch circles, or the number of teeth, and something to determine the size of the describing circles. Manufacturers have found by experience what are the best ratios of describing circles to pitch circles, and gears are designed according to those ratios. It is not well to have the diameter of the describing circle greater than $\frac{5}{8}$ the diameter of the pitch circle, and it is better to have it smaller. If a set of gears is to be made, any one of which is likely to run with any other one, the same size describing circle must be used for the faces and flanks of all the gears; and this describing circle is often taken $\frac{5}{8}$ the diameter of the smallest gear of the set. Sometimes when two gears are not part of an interchangeable set, but are designed to run with each other only, the diameter for the describing circle for the flanks of each gear is made equal to the radius of that gear; and when this is the case, the flanks are radial straight lines; or, as it is usually stated, the gears have radial flanks.

In Fig. 114, the two describing circles are of the same size and equal to the radius of the smaller gear, thus giving radial flanks on this gear. Let us proceed with the design of this pair of gears, given dimensions as follows: Gears to be 4 pitch (that is, as explained previously, 4 teeth per inch of pitch diameter); gear A to have 12 teeth; gear B 16 teeth; addendum equal to the diametral pitch; clearance equal to $\frac{1}{8}$ the addendum; describing circles each equal to radius of gear A.

Method of Drawing Gears. The steps in the process of drawing the gears are as follows:

1. Calculate the diameters of the pitch circles.

2. Draw the center line XY on the paper; and on this center line locate the centers A and B a distance apart equal to $\frac{1}{2}$ the sum of the two pitch diameters. About these centers draw the pitch circles, of diameters as calculated. This will make the pitch circles tangent at the pitch point P.

3. Calculate the addendum and dedendum, adding this amount to and subtracting from the radii of the pitch circles. Then draw the addendum and dedendum circles with the radii thus found.

4. Draw the root circles with radii equal to the radii of the pitch circles minus an amount equal to the dedendum plus the clearance.

5. Draw the describing circles tangent to each other and to the pitch circles at the point P.

6. With the describing circle C rolling on the outside of the pitch circle of A, generate the epicycloid PF, continuing it until it meets the addendum circle of A. With the describing circle D rolling on the inside of the pitch circle of A, on the opposite side of line of centers from which the circle C rolled, generate the hypocycloid PG. Since the diameter of D is equal to the radius of the pitch circle of A, the hypocycloid PG will be a radial line; and consequently, after the student has become familiar with this fact, it will not be necessary actually to roll the circle to generate such a hypocycloid. The epicycloid PF and the hypocycloid PG together form one side of the tooth of gear A.

7. Divide the circumference of the pitch circle into as many equal parts as the gear has teeth, and through these points draw curves like the curve GPF. This may be done by making a templet of stiff paper that will just fit the curve GPF, and by means of this templet, transferring the curve to the points *1*, *2*, *3*, etc. Next find the points a, b, d, etc., half-way between *1* and *2*, *2* and *3*, etc., since there is to be no backlash, and through these points draw curves similar to GPF, but turned so as to curve the other way. Now, by filling in with full lines that part of the addendum circle between the points F and N, R and S, etc., and filling in the root circle between T and V, etc., we have the outline of the teeth on the gear A. In practice, instead of making sharp corners at T and V, as shown by the dotted lines, fillets are put in with arcs of circles, these fillets being made as large as possible and still allowing space so that the corner of the teeth on the other gear shall not strike.

8. Construct the teeth on the gear B in the same way as the teeth on A were constructed, the describing circle D generating the epicycloid PH by rolling on the outside of the pitch circle of B, and the describing circle C generating the hypocycloid PE by rolling on the inside of the pitch circle of B. The hypocycloid is not a straight line in this case, as the diameter of C is not equal to the radius of the pitch circle of B.

The calculations for the above case are as follows: 4 pitch means 4 teeth per inch of diameter; and as there are 16 teeth in B, its diameter will be $\frac{16}{4}=4''$; 12 teeth in A will give $\frac{12}{4}=3''$ diameter.

The addendum for a standard machine-cut gear is usually made equal to the dedendum, and is equal to the reciprocal of the pitch.

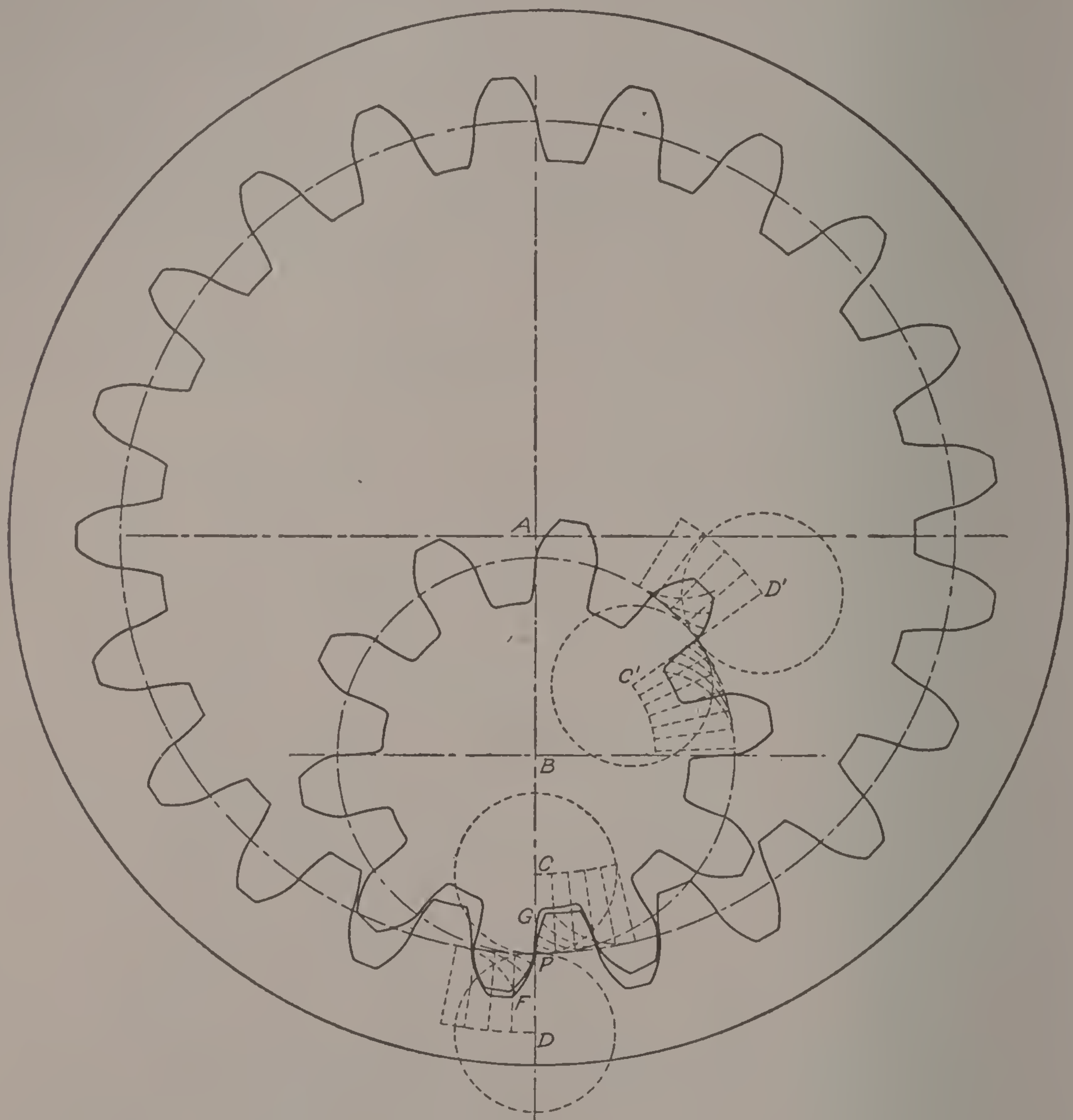


Fig. 115. Layout for Annular Gears

Hence, to find the addendum and dedendum in the present case, take the reciprocal of 4, which is $\frac{1}{4}''$.

The clearance, being $\frac{1}{8}$ the addendum, is equal to $\frac{1}{8}$ of $\frac{1}{4}=\frac{1}{32}''$.

If the student tries to follow the above description by actually drawing these gears, it will be found necessary to draw them to about 3 times their actual size in order to bring out the points clearly. That is to say, the pitch circles should be made 9″ and 12″; the

addendum and dedendum $\frac{3}{4}''$; the clearance $\frac{3}{32}''$; the numbers of teeth, of course, remaining 12 and 16.

ANNULAR GEARS

An annular gear is a ring with teeth on the inside of it. Fig. 115 shows such a gear, with center at *A*, meshing with its pinion. The

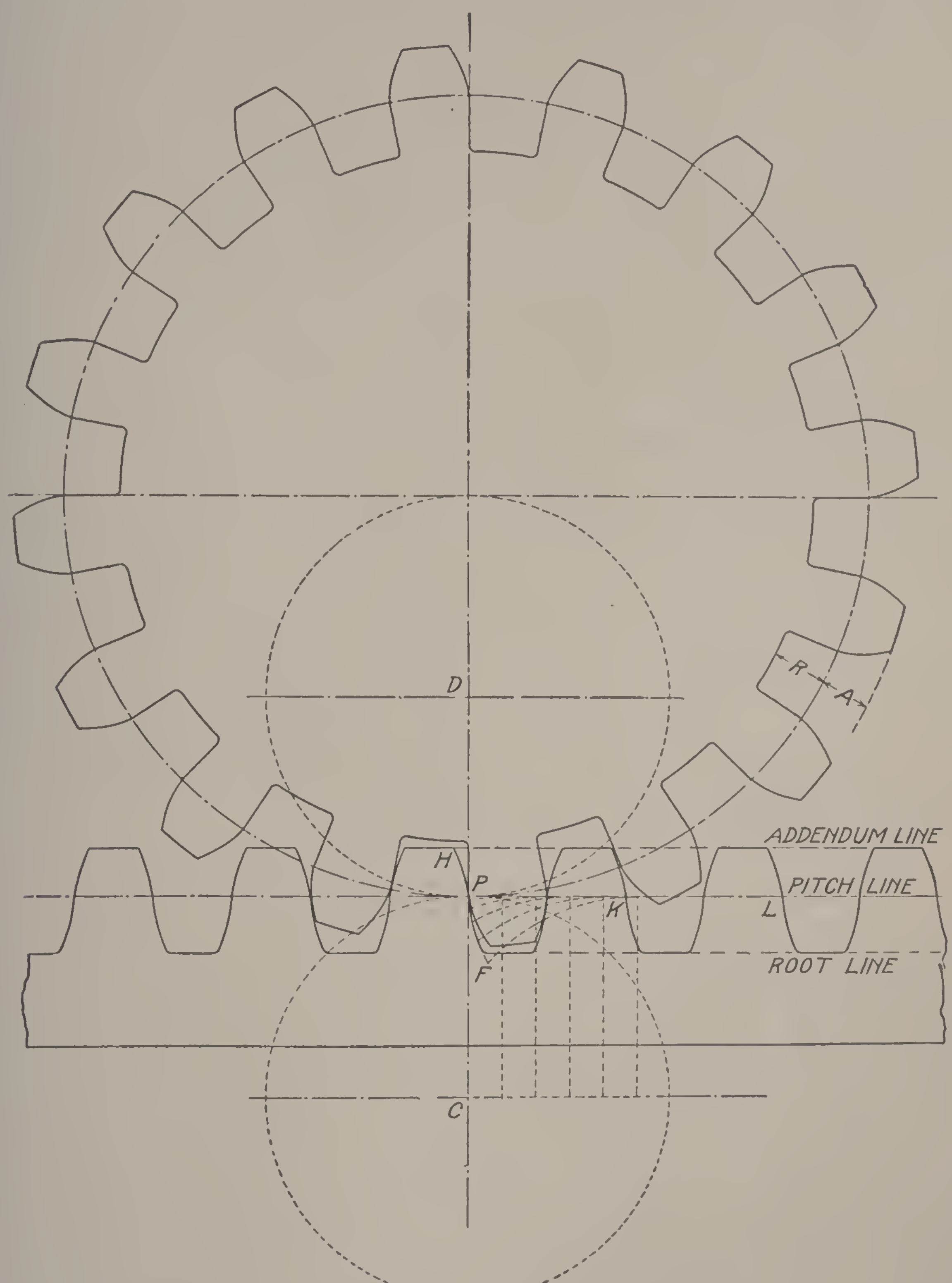


Fig. 116. Construction for Epicycloidal Rack and Pinion

method of drawing such a pair of gears is similar to that just described for two spur gears. Here the circle *C*, by rolling on the inside of the pitch circle of *A*, generates the faces of the teeth on *A*; and the circle *D*, by rolling on the outside of the pitch circle of *A*, generates

the flanks of the teeth on A. The shape of the teeth of the pinion in the figure is found with the same describing circles placed at C' and D' to avoid confusing the lines.

In designing an annular gear and pinion, the diameter of the gear must never be so small that the distance from center A to center B shall be less than the sum of the radii of the two describing circles. If this should be the case, the teeth would interfere with each other.

RACK AND PINION

A rack is a gear whose pitch line is a straight line instead of a circle. Fig. 116 shows an epicycloidal rack in gear with a 16-tooth pinion. The describing circles are of the same size in the figure, although they might be of different sizes. The teeth on the pinion are drawn as described for Fig. 114, the construction lines for drawing them not being shown. The curves which form the faces and flanks of the rack are cycloids. The describing circle C, rolling on the pitch line of the rack, generates the cycloid PF, which forms the flanks of the rack teeth; and the describing circle D, rolling on the pitch line of the rack, generates the cycloid PH, which forms the faces of the rack teeth. The addendum and root lines are drawn parallel to the pitch line, and at a distance from it equal, respectively, to the distances A and R of the pinion. The teeth are spaced off on the pitch line of the rack by laying off the distances PK, KL, etc., equal to the circular pitch of the pinion.

INVOLUTE GEARS

Involute Compared with Cycloidal Gears. We have seen in the preceding pages how the outlines of cycloidal gear teeth are generated by a point in a circle rolling on the pitch line. We have noted that the point of contact between the teeth is always somewhere on the describing circles, drawn tangent at the pitch point. The outlines of involute gear teeth, which are far more common than cycloidal teeth, are generated by a somewhat similar process. In the case of the involute, however, the describing point is located on a straight line, rolling, not on the pitch circle, but on another circle inside the pitch line, known as the base circle. The result of rolling a straight line, as noted above, is the same as if we stand up on the drawing board a small cylinder of diameter equal to the base circle, fasten one end of a string to some point in its circumference, and then

allow the string to unwrap from the cylinder, a pencil point at the free end of the string marking on the paper below it the involute curve.

Design of Involute Gears. The method of drawing the involute curve is shown in Fig. 117; and it is obvious from this figure that the curve can never extend inside the base circle, although it may go any distance above it.

Fig. 118 shows a pair of gears with involute teeth, drawn according to the principles stated below. The circular pitch and diameters of pitch circles are calculated in the same way as described for cycloidal gears. The centers *A* and *B* are chosen, and the pitch circles drawn tangent at the pitch point *P*, as before. In involute gears, the point of contact between the teeth is always somewhere on an inclined line, *CD*, passing through the pitch point. The angle which this line makes with the tangent *XY*, is called the angle of obliquity (equal also to *PBD*). Its size has an important bearing on the action of gear teeth; and there are special conditions which, for the best tooth action, would call for widely different angles. It is not well, however, to have the angle of obliquity of different values, as it would then be impossible for any two gears to run together, except those based on the same angle. The angle of obliquity which has been quite generally adopted and which seems to fulfill the average conditions best, is 15°. In the present case, therefore, draw the line *CD* at an angle of 15° with the tangent *XY;* with *A* and *B* as centers, draw circles tangent to *CD;* these circles are called the base circles. The addendum, dedendum, and root circles are then drawn at the same relative distance from the pitch circles as in the case of cycloidal gears. The spacing of the teeth is now accomplished by stepping the dividers, set to the circular pitch, around the pitch circle. At any convenient points on the base circle, as *G* and *E*, generate the involutes in

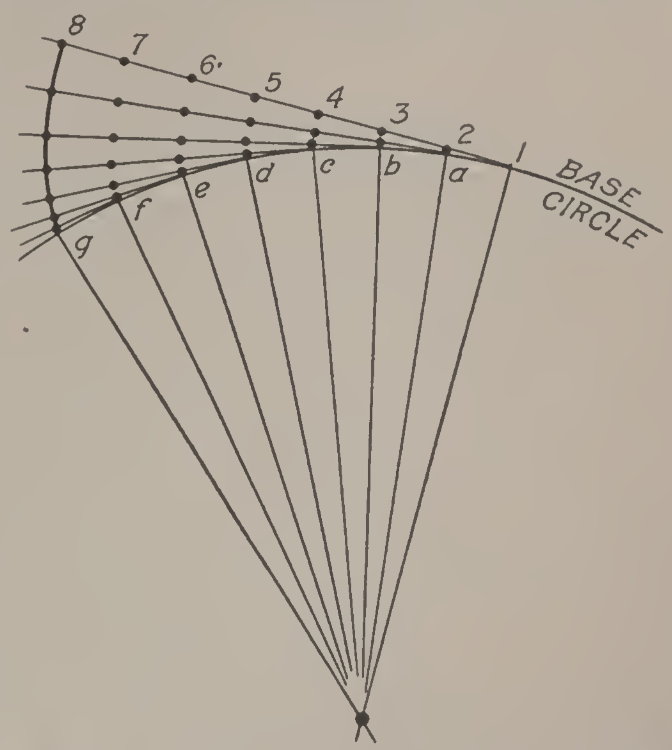


Fig. 117. Method of Drawing Involute Curves

accordance with the method of Fig. 117, or as explained in Mechanical Drawing, Part II. Then, by the tracing-cloth method, or by the use of a templet fitted to this curve, draw in the tooth curves at points *R*, *S*, *T*, etc., on the pitch circles. This gives us the working part of the teeth, and the remainder of the tooth to the root circle consists of a radial line. Fillets are put in at the bottom of the teeth, as in the case of cycloidal gears.

As has been stated above, the point of contact between the teeth is always somewhere on the line *CD*; it is therefore obvious that, if the circle struck through the top of the tooth on one gear cuts the base circle of the other gear at a point outside of point *C*, there can

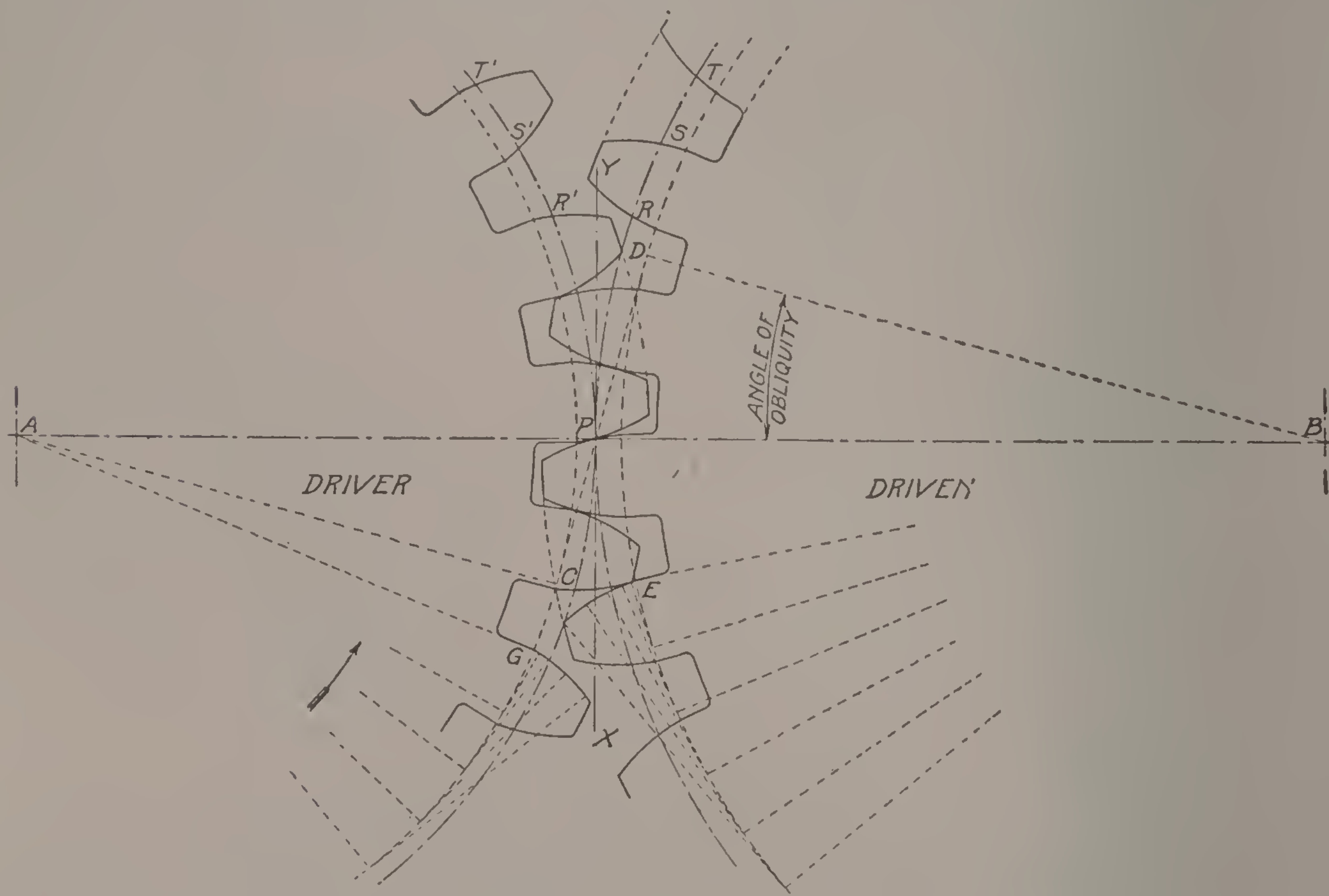


Fig. 118. Diagram Showing Pair of Involute Gears in Mesh

be no true contact at the top of the tooth. Instead of there being true contact, the top of the tooth will actually dig into the lower portion of the tooth of the other gear. This is known as interference, and is overcome by slightly rounding off the top of the tooth down to the circle through point *C*, so that it will clear. Since the path of the point of contact is along the line *CD*, this line also represents the common normal to any pair of teeth in contact, and therefore is the line of pressure between the teeth. The obliquity of this line of pressure to the line of centers *AB* causes a thrust between these centers, tending to force the gears apart; and this has been

considered an objection to the use of involute gears. With the standard 15° involute, however, experience has shown that this thrust is ordinarily of small importance. A similar thrust exists in cycloidal gears, but is constantly changing in value, being a maximum at the beginning and end of contact of a pair of teeth, and zero when the pair of teeth are in contact at the pitch point. It will be noted that the involute tooth is of simpler outline than the cycloidal, being a single curve instead of a reverse curve. If the exact distance between the centers A and B of a pair of involute gears be not maintained, owing to wear or to some other cause, the gears will still continue to run perfectly together; whereas in the case of cycloidal gears the action is seriously impaired by such a condition.

BEVEL GEARS

Bevel gears are used to connect shafts whose axes intersect. The angle between the shafts is not necessarily a right angle, but this is the most common angle used. Fig. 119 shows a pair of bevel gears connecting two shafts whose axes intersect at a right angle.

The cones OPA and OPB are called pitch cones; the cones CPB and DPA, normal cones, and it is on these normal cones that the outlines of the teeth are laid out; BP and AP are the pitch diameters of the gears, and are found from the pitch and number of teeth just as the pitch diameters of spur gears are found.

Design of Bevel Gears. To draw such a pair of gears, we must have given the angle between the shafts, the pitch and number of teeth in each gear, and the face of the tooth PE. The outlines of the teeth may be either involute or cycloidal; the addendum, dedendum, and clearance are determined by the same empirical rules as were applied to the other gears which have been discussed.

Referring to Fig. 119, the gears shown are 2-pitch, 16 and 20 teeth, respectively, with face PE equal to 2 inches.

According to previous understanding, the addendum or the dedendum for a standard tooth is the reciprocal of the diametral pitch—or, in this case, $\frac{1}{2}''$. Making the clearance $\frac{1}{8}$ of the addendum, would give $\frac{1}{8}$ of $\frac{1}{2}'' = \frac{1}{16}''$. The teeth are of the involute form, with an angle of obliquity of 15°. Choosing point O, draw the lines OC and OD, making an angle of 90° with each other; calculate the pitch diameters of the gears; lay off on OC the distance OH, equal to $\frac{1}{2}$

the pitch diameter of the smaller gear; and through H draw a line perpendicular to OC. In like manner lay off on OD the distance OJ, equal to $\frac{1}{2}$ the pitch diameter of the larger gear; through J draw a line perpendicular to OD, meeting the perpendicular which is

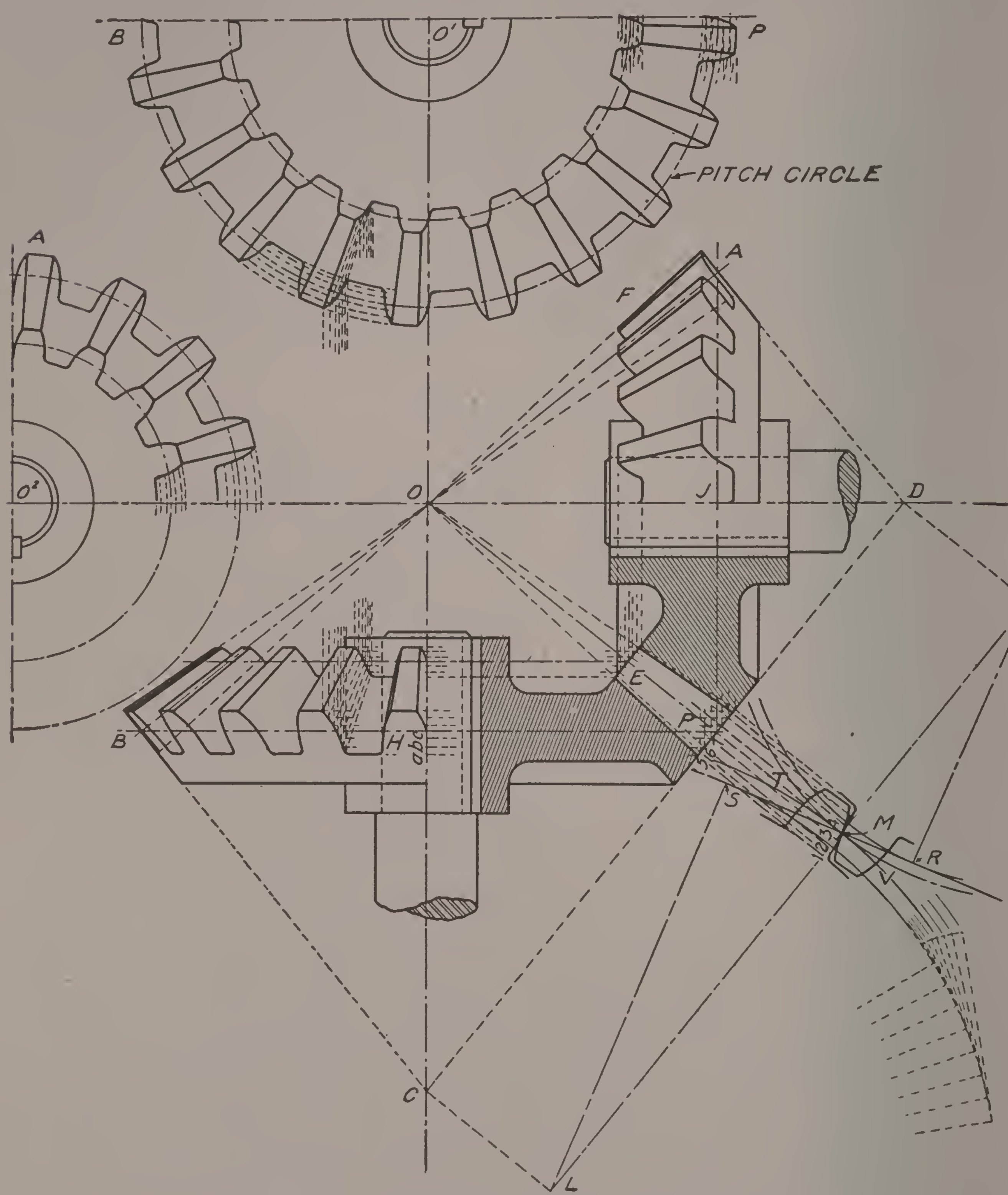


Fig. 119. Construction Diagram for Pair of Bevel Gears

drawn through H at P; and make HB equal to HP, and JA equal to JP. From A, P, and B, draw lines to O, producing the pitch cones; through P draw CD perpendicular to OP, meeting OC and OD in C and D, respectively. Join CB and DA, and we have the normal cones. Through C, P, and D, draw perpendiculars. Draw

LMK parallel to CPD at any convenient distance. Draw arcs of circles tangent at the point M. These arcs are now to be treated as pitch circles on which to design the tooth curves, in exactly similar fashion to the method already outlined for spur gears.

Through point M draw the line of obliquity SR, and draw the base circles tangent to this line. With the addendum chosen as above, equal to $\frac{1}{2}''$, it will be found that the addendum circle of the larger gear will cut the line of obliquity beyond the point R, where SR is tangent to the base circle of the pinion. This means that true contact cannot occur at the top of the gear tooth, so the tooth should be slightly rounded off, to prevent interference with the flank of the pinion. The limit of this rounding-off of the point of

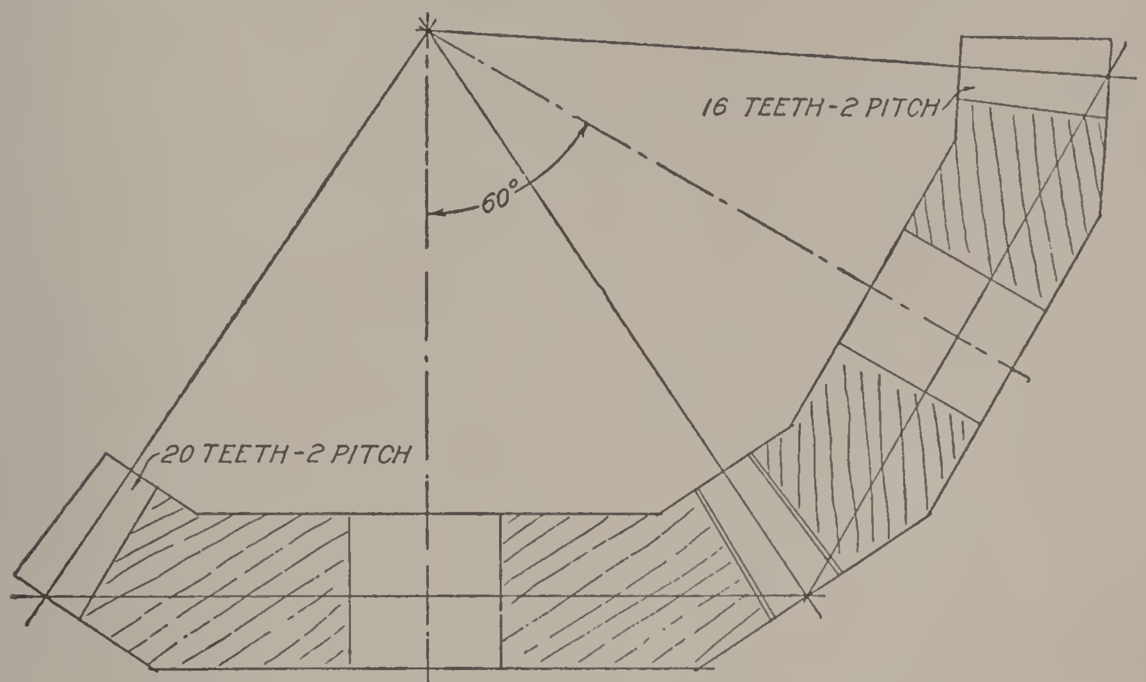


Fig. 120. Skeleton Diagram for Bevel Gears not at Right Angles

the tooth is determined by striking a circle with center L through the point R, as it is obvious that below this point on the tooth of the gear there will be true involute contact. The root circles are drawn by setting off the clearance, as in the preceding cases. One tooth on each gear is drawn on the development of the pitch circle, and the completion of the drawing of the teeth in the several views of the gears is merely a problem in projection.

With L as a center, draw a series of arcs (shown dotted) cutting the tooth which was drawn on the pitch circle, and the line LMK, at *2, 3, 4,* etc.; from *2, 3, 4,* etc., draw lines perpendicular to CD, cutting CD at *5, 6, 7,* etc.; from these points draw lines to O; along PO lay off PE; through E draw a line perpendicular to PO, cutting

50, *60*, etc.; and from the points of intersection draw other lines parallel to PB. With center O', taken at any convenient place on CO prolonged, and with radii equal in turn to *a5*, *b6*, etc., draw circles as shown. On the circle which is drawn with HP as a radius (marked "pitch circle"), space off the circular pitch; and on each of the circles in turn, lay off the teeth of the same width as they are on the corresponding circles drawn through *1*, *2*, *3*, *4*, etc. The rest of the construction can be understood by a careful study of the figure. The other gear is drawn in the same way.

Intersecting Angles Other than 90°. The drawing of the teeth for bevel gears whose shafts intersect at another angle than a right angle, is accomplished by following out the same principles as noted in the case at hand. The skeleton outline of such a pair of gears is shown in Fig. 120, the angle between the axes being 60°. These gears are 2-pitch, 16 and 20 teeth, respectively, the same as in the previous case; and their construction affords an interesting comparison therewith.

General Manufacturing Practice. To draw the teeth on a pair of bevel gears as described in Fig. 119, is a tedious process and requires considerable patience and drafting skill. It is really little more than an exercise in advanced projection drawing, but, as such, is valuable to the student. It must not be thought, however, that to detail a pair of bevel gears for manufacture, such a drawing is necessary. Usually, standard proportions of teeth are specified, and the detail of the gears is comparatively simple. An illustration of a pair of bevel gears of standard proportions of teeth, detailed ready for the workman's use, is shown in Fig. 39, Machine Drawing, Part I, and it is seldom necessary to show more.

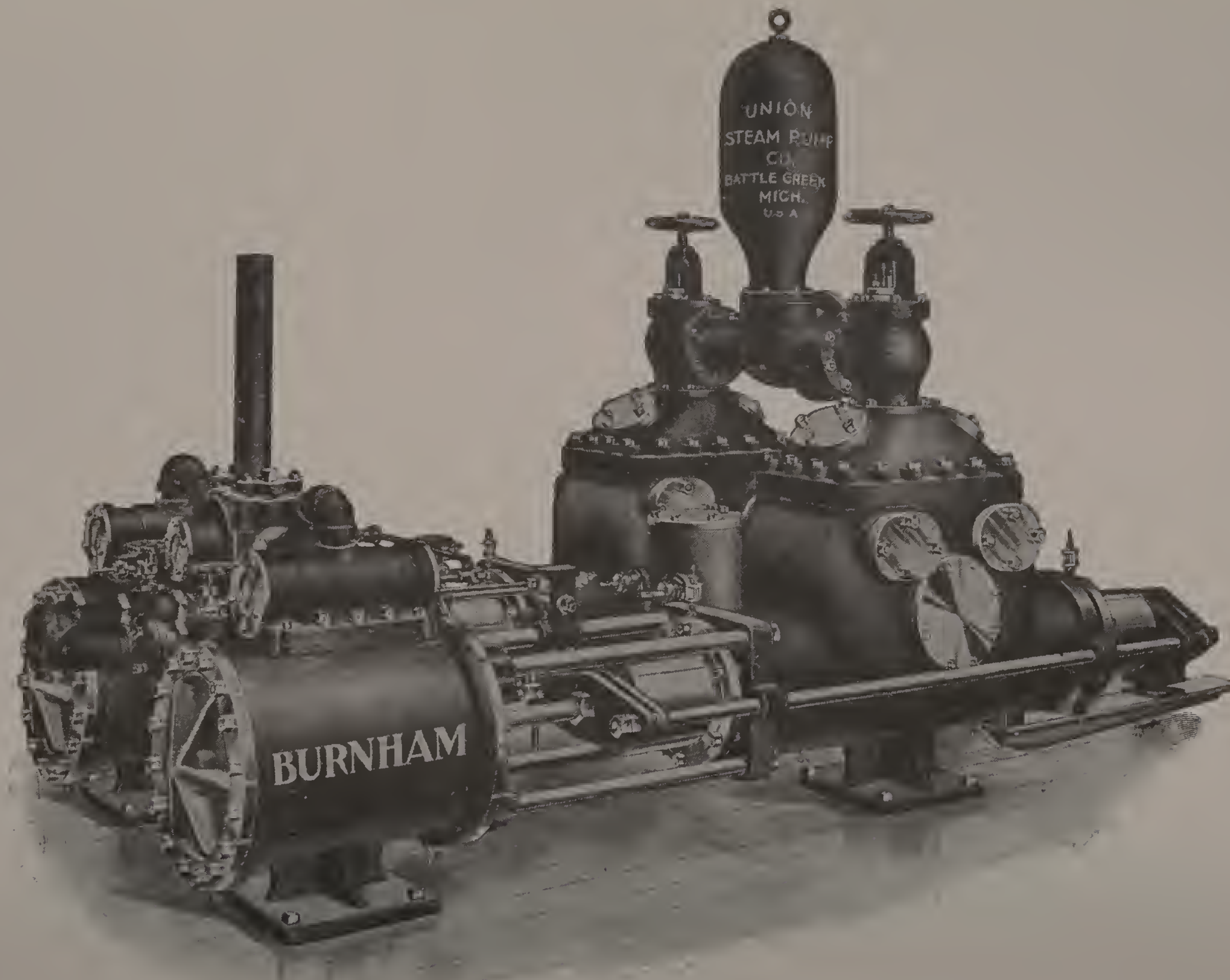
General Remarks on Gear Teeth. The foregoing study of the outlines of gear teeth is given in brief and elementary form. The student cannot hope to gain a familiar comprehension of the action going on between the teeth of gears, without going more deeply into the subject than is possible in these pages. The action of gear teeth is one of the most complicated subjects to investigate and understand, as with each new condition of number and type of teeth, new points of action are developed.

A good practical article on gear teeth is "A Treatise on Gear Wheels" by George B. Grant; and the student is referred to this book for a further study of the subject.

There are many special points to be observed in designing the outlines of gear teeth, in order to insure the best operation of the gears. These points cannot be well explained without the actual undertaking of the design of the teeth. If the student wishes to familiarize himself with tooth action, he cannot do better than to choose a variety of cases, and lay out each one, studying the several points as they come up.

It should be remembered that the action of a small pinion, meshing into a large gear is considerably different from that of two large gears meshing into each other.. With certain relative numbers of teeth of gear and pinion, as many as three pair of teeth may be in contact at all times; while, in certain other combinations, but two are in contact at all times, and in certain others only one. Changes in the tooth dimensions, diameters of describing circles, angles of obliquity, etc., alter all these conditions, so that there is an endless variety of combinations, each of which presents some new feature only to be understood by actual layout of the particular case.

In gear-tooth work, the student will often find it an advantage to make the layouts to double the actual size, and sometimes larger. A fine, hard pencil must be used, and extreme accuracy in determining the points must be adhered to. The layout of gear teeth is one of the severest tests of the draftsman's ability in line work.



BURNHAM TWIN PUMP—OUTSIDE-PACKED PLUNGER TYPE
Courtesy of Union Steam Pump Company, Battle Creek, Michigan

MACHINE DRAWING

PART III A—MECHANICAL

WORKING SHOP DRAWINGS

In Mechanical Drawing, Parts I to III, inclusive, the fundamental principles were explained and illustrated. In Machine Drawing, Parts I and II, the production of working drawings has also been discussed to some extent, and the usual characters and symbols explained and applied. The elementary work already outlined has been treated chiefly from the standpoint of correctness of line representation considered by itself, without a detailed study of the use to which the drawings so produced are to be applied.

Evidently this is the proper method, for the student should gain a thorough understanding of the principles which underlie line representation before attempting to apply them to any extended practical use. In all of this preceding work it was intended that the theoretical principles should overshadow any incidental references made to practical application, however true and pertinent the latter may have been for purposes of illustration. Hence, before taking up any advanced work, the student should fully realize the importance, in fact, the absolute necessity, of thoroughly understanding the fundamental principles which have been outlined in the preceding books.

At this point the student must realize that a lack of proper elementary and fundamental training will make him "go lame" at every point of his course, and probably prevent the attainment of proficiency which otherwise would naturally and almost instinctively come with advanced study. It is thorough and ready knowledge, always at his fingers' ends, of all the principles of Mechanical Drawing, which makes the expert draftsman.

Plan and Scope of Advanced Work. *Utility the Guide.* It is now intended to throw an entirely different light on the matter, and

view the subject of Machine Drawing from a purely practical standpoint, that of utility. It is assumed that the student understands and can use the principles which have been previously discussed.

If in a working shop drawing we choose to modify any of these theoretical principles, it will be because of increased value in the utility of the drawing. For example, we may desire to omit some portions of an elevation or plan or side view of a complicated casting, because certain details will thus be more clearly brought out. We may make a "zigzag" section to show construction which, by absolute fidelity to theoretical principle, would be confused, or hidden in a maze of dotted lines. We may find it convenient to place in some unoccupied corner of a drawing a layout which could not be in the least justified by any rule of projection. A multitude of transgressions like these occur on good drawings, and they are certainly justifiable from the standpoint of utility, which is the true ultimate end sought for in a practical shop drawing.

These variations from the theoretical are not strictly conventionalities, because they are not classified or established, so far as we know, but are the spontaneous outgrowth, as the occasion demands, of the draftsman's purpose to make his drawing one of greatest utility. He can, however, safely transgress a principle only when he thoroughly knows the principle; otherwise a blind deviation from the theoretical path will inevitably lead to difficulty.

All of the above is intended to impress the student with the idea that theoretical principles are his best, in fact, his only tools to work with; but they are not "self-hardening," like "mushet" steel; they are like the finest grade of tool steel, which must be tempered and ground and used with the best judgment of the operator, to secure the most satisfactory results.

Student Drawings. A student's early drawings are usually unsatisfactory, even to himself. Somehow they do not look like those seen in shops, and as a rule he is unable to see why this is so. Of course the difference is to some extent due to the experience of the professional draftsman. However, the superior results of the latter's work are attained largely through his systematic and workmanlike habits of execution. It should encourage the student in his early attempts to know that these essentials to the infusion of life and shop spirit into a drawing can be analyzed, out-

lined, and grasped at the outset by earnest, intelligent effort, and really good workmanlike results obtained. To discuss and, if possible, to impart these essentials of a working shop drawing to the student, is the purpose of the present book.

Essential Requirements. The two chief essentials of a shop drawing, under which general heads a multitude of detail requirements can be summed up, are:

(1) Absolutely complete and definite instructions from designer to workman.

(2) Least possible cost in dollars and cents of production of the drawing measured by the draftsman's time.

It makes no difference how much we may attempt to disguise these two elements, the fact will still be apparent that "*complete instructions furnished for the least money*" is what the manufacturing shop is after, and what will be assumed as a basis for judgment as to highest commercial utility.

Completeness of Drawings. As to the first point, that of completeness and definiteness of instruction, there must be no question of degree. If the information which the drawing furnishes is positive and complete, the drawing is good. If doubt arises in the workman's mind as to what the designer intended by a certain line or dimension, or if the dimension be omitted, the drawing is bad. There is no middle ground. The instructions are either present or absent, and the drawing good or bad accordingly.

The workman of today is not permitted to assume dimensions or shape. It is his business to execute the draftsman's orders; it is, however, often his privilege to choose his own way of doing it, but further than this modern practice does not allow him to go. He is held as rigidly to the orders specified by the drawing as the locomotive engineer is held to his bit of tissue telegraphic order to proceed, without which he dare not enter the next block. The drawing is supreme; it is official; it must be plain, direct, and all-sufficient. It is the draftsman's business to make it thus, and he is not a draftsman until he does.

This idea of positiveness must be thoroughly absorbed by the student. Positive action must be a habit which controls his every move, which marks every dimension he prints, which directs every line he draws. Every line must mean something, must have a

definite reason for existence, must be necessary to illustrate the idea which he wishes to convey to the workman, and every line must be a definite measurable distance from every other line, so that its location is fixed beyond a doubt. Lines which mean nothing, and cannot be measured, have no place on the drawing; they only confuse it.

A good picture of a machine could scarcely be called to the same service as a good drawing of it. The picture might give us an excellent idea of the machine, but for the purpose of the actual construction the picture is useless, while the drawing is of positive value. This value exists simply because of, and in proportion to, the completeness of detail which it shows. Hence in making a shop drawing the picture idea is entirely subordinate to the idea of utility, the latter, in fact, being the measure of its value.

There are certain classes of drawings—of which the Patent Office drawing is a good example—in the making of which the picture idea is predominant. Here the purpose is to illustrate mechanisms, not construct them; hence the function of the drawing is in no wise that of the working shop drawing, and as such does not fall within our discussion.

Cost of Producing Drawings. The second general element involved in producing shop drawings is their cost, as measured by the draftsman's time. It is somewhat subordinate to the first element, for the drawing must be a good one, judged by an absolute standard, whatever the time or cost necessary to produce it. Cost, however, is an important item, and cannot well be overlooked. It is inevitable that in any enterprise economy will ultimately be sought, whatever extravagance an imperative original demand may have permitted. This is as true in the production of drawings as in the case of manufactured articles of trade. Drafting-room labor is a relatively high-priced service, and the salary list easily assumes considerable proportions, so that wasteful excesses count up rapidly. One of the qualifications of proficiency invariably required for this department of shop organization is rapidity of execution. This is not as dependent upon personal traits as at first might be supposed. A man may so husband his time and direct his efforts that he will easily distance his neighbor of more rapid motion. The latter may have less ability to make his energies count, and lack of judgment

as to when just enough, and no more than enough, energy has been expended on his drawings. From the standpoint of utility, the function of a drawing is fulfilled when it has reached the stage that it *completely* instructs; more time spent in elaboration is wasted, and is an unnecessary and therefore extravagant expenditure. The student must fully realize this. In his earnestness to produce finished and complete work he must constantly strive to accomplish results in the least possible time. This does not mean careless haste; far from it. A complete shop drawing cannot be made by short cuts, but through a systematic building of line on line, dimension on dimension. This is in sharp contrast to a haphazard habit of developing a drawing, first a line here and then a figure there, with no definite purpose in mind, and no hint as to when the drawing is actually completed.

The one method constitutes the efficient draftsman who works easily, receives a high salary, and is worth it, because he wastes no time in unnecessary labor. The other marks his unfortunate brother, plodding laboriously far behind, receiving a small pittance per hour, and worth less, because he does uncalled-for labor, and loses his definiteness of purpose in a maze of unexplainable lines and figures.

A working shop drawing, commercially considered, may well be defined as being *"Complete instruction from designer to workman issued at minimum expense."*

This definition should be memorized by the student, and constantly kept in mind while making a drawing. The preceding pages should be re-read with this in view until the full spirit is appreciated.

The maxim as given above, if faithfully adhered to without modification, answers nearly every question that can be raised as to the excellence of a drawing. It can be used as a standard of judgment, whatever system of lines or symbols may be in vogue. It permits a draftsman to adjust himself to the rules of any shop or drawing room, and yet produce a good drawing and satisfy his employer.

A drawing which is cheaply produced yet at the same time does perfectly that for which it was made, viz, conveys complete instruction, is beyond commercial criticism.

Method of Procedure. As the general objects to be attained in a working shop drawing have now been presented, it is necessary to indicate in detail how the work may be properly accomplished. In order to do this, it is proposed to produce systematically a full set of working drawings of a familiar and comparatively simple machine. The methods used will be those of a designing detail draftsman, producing commercial work fit for shop use. In the progress of the work, from its beginning in the rough, though accurate, pencil layout, to the completion of the tracings and the order sheets, the same bold style, clearness, directness, and businesslike spirit which the shop atmosphere and surroundings would naturally supply will be emphasized, and so far as possible imparted to the student. It is expected that the student will follow the text closely and study the plates carefully, endeavoring to familiarize himself with every detail illustrated. The more closely he is able to apply himself in this respect the better will he be able to partake of the life and spirit which is intended to be conveyed, and without which the true character of the work can be but poorly developed.

Incidentally, several purposes will be fulfilled by this treatment.

Practice in Reading Drawings. Ability to read drawings quickly and intelligently is almost as important as making them, and it is expected that the study of the plates, with a view to thoroughly understanding every line, will develop proficiency in the art of reading drawings.

Discussion of Tools and Machine Parts. The discussion in the text of not only the form of the machine parts themselves, but also the tools and shop processes to produce them, affords considerable insight into the influences affecting good machine design. Without introducing any mathematical analysis or investigation, which is beyond the province of this book, much practical consideration as to the restrictions imposed by existing shop methods upon theoretical construction will be suggested, and the student encouraged to use his judgment thereon.

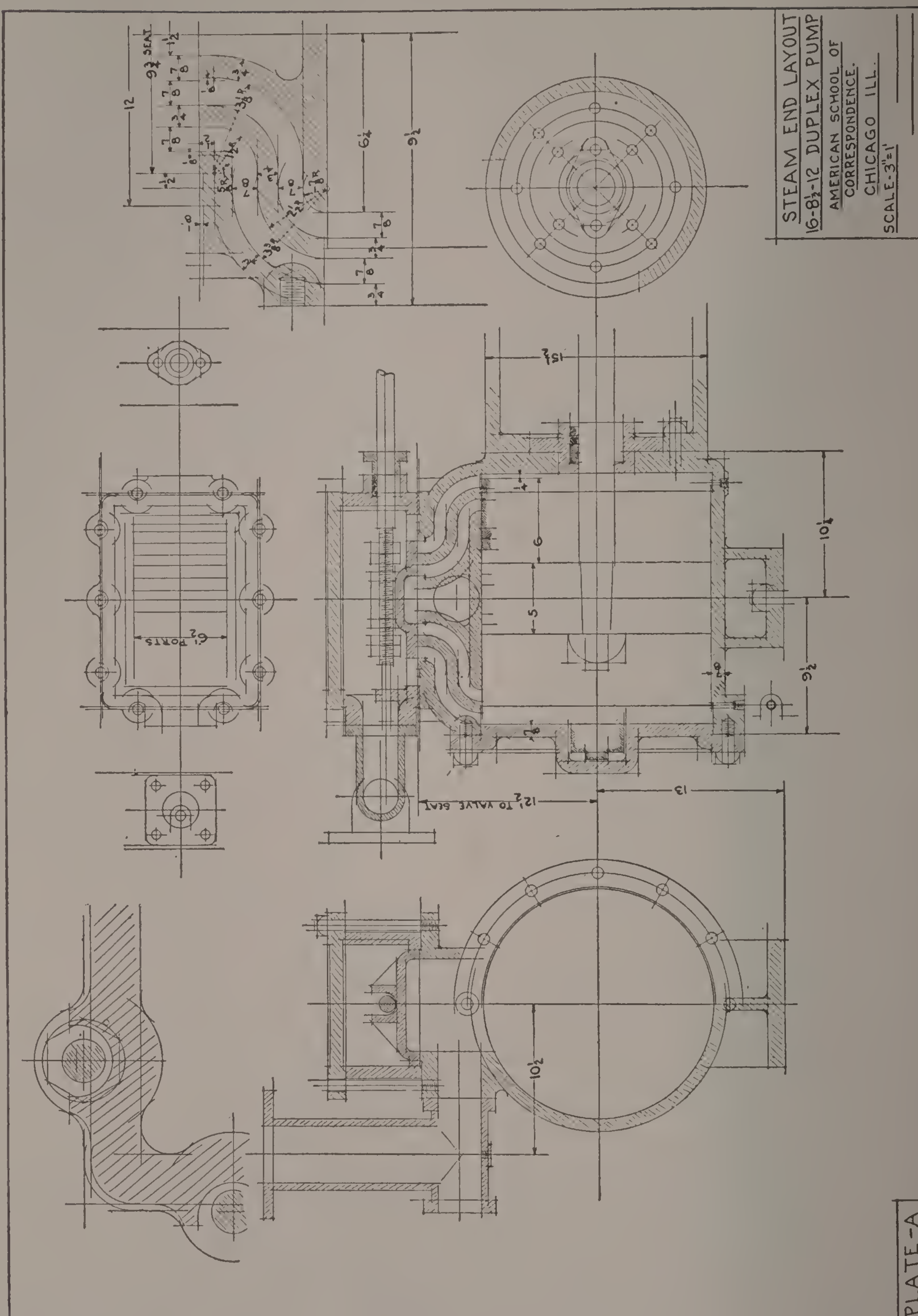
Imitation of Pencil Sketches. In the preliminary layouts the actual "sketchy" appearance of the pencil drawing will be imitated as far as possible, so that the student himself may imitate and catch the bold dash, yet fine accuracy, of the linework, which is characteristic of the expert draftsman.

Making of Complete Drawings. The completeness of a *set* of drawings is as important a lesson as the completeness of each drawing itself. In this is involved the proper arrangement and classification of details, the foundation layout, and the system of order sheets for getting work into and through the shops. This is a feature which very strongly affects some of the finishing touches to a drawing, for it is so easy to omit a "few last things" and turn in an uncompleted sheet. Every draftsman knows how many little things come up toward the close of a job involving complete drawings of a machine, and how strong the tendency is to omit them, and relieve himself of somewhat tedious details. The result is irritation and delay when the drawings get into the shop, and they return to the drawing room to be fixed up at a time probably inconvenient for all parties concerned. A good draftsman will turn in a *complete* set of *complete* drawings. It is highly important that the student grasp this idea, and study his work accordingly.

DUPLEX PUMP PLATES

Reasons for Choice of Pump Specifications. The typical set of plates chosen for this book in fulfillment of the above purposes, takes up the study of a simple, duplex steam pump. This particular type of machine represents the simplest and most elementary form of the steam engine in modern use in respect to valve gear and controlling devices. It is not an economical machine, yet its principles lie at the foundation of the economical high-speed engine, the latter being produced through a modification of the uneconomical valve gear such as is found on a pump of the type chosen, rather than through any radical change of construction as to the body of the machine. Hence the study of a steam pump may well precede that of higher forms of the steam engine. It is hoped that the study will so interest the student that he will be led to further investigation and development not only of the steam engine itself, but of that highly important division of modern engineering—pumping machinery.

Thus we note another point of advantage in the study as outlined. The power end of the machine introduces us to the steam engine; the load end is the beginning of the engineering of pumping machinery.


STEAM END LAYOUT
16-8½-12 DUPLEX PUMP
AMERICAN SCHOOL OF
CORRESPONDENCE.
CHICAGO ILL.
SCALE-3"=1'
PLATE-A
6½ PORTS
12½ TO VALVE SEAT

Rating of Pump. A steam pump is rated by the bore of its cylinders and length of stroke, all being given in inches. A "$16 \times 8\frac{1}{2} \times 12$ pump" means that the steam cylinder is 16 inches in diameter, the water plunger $8\frac{1}{2}$ inches in diameter, and the nominal length of stroke 12 inches. These sizes are always given in the same order, beginning with the diameter of the smallest cylinder (in case there is more than one), then the diameter of water plunger, the common stroke of both being placed last. This expresses to the mechanic the rating of the pump in the clearest style and briefest language.

The pump illustrated here is designed for standard service, operating under a steam pressure not to exceed 100 pounds per square inch, water pressure not to exceed 150 pounds per square inch, and the rated capacity based on an average piston speed of 100 feet per minute being about 550 gallons. This requires that each side of the pump shall handle 275 gallons and, being double acting, shall make 100 reversals or 50 double strokes per minute.

PLATE A. STEAM END LAYOUT

This plate illustrates, as nearly as reproduction can accomplish, the pencil layout of the steam end. It is the first work of the designing draftsman. The drawing as shown is exactly the type of layout which he would turn over to a detail draftsman, whose duty it would be to work up detail shop drawings therefrom.

Characteristics of a Layout. The character of this drawing should be carefully studied. Remember that it is a layout, nothing more; also bear in mind that it is an exact, measurable working sketch. Attention is called to the sharpness of the lines, especially to the clean-cut intersections. Note the boldness, dash, and business-like style, the freehand cross-section lines roughly put in. There is no hesitation or worry as to where the end of a line shall be, or whether it crosses other lines which it theoretically should not. The intersections are allowed to indicate the termination of lines, and the rough section lines pick out the parts and separate them clearly to the eye. There is, in this layout, the spirit of confident, definite, and rapid action, with no thought for absolute finish in linework, but with every thought for absolute results as to measurable dimensions.

Relations of Different Drawings. The data for the production of Plate A by the student are rather more complete than he would usually find in practice. Plates B, C, and D show many details fully.

The steam cylinder and head, however, as shown in Plate B, are not dimensioned, and the student's problem is to produce this plate complete, with finish marks, dimensions, and necessary data for a working drawing. In order to do this it is first necessary to work up Plate A with exactness, in pencil, and see that all parts go together properly. Then the detail of cylinder and head may be made separately by measurement of the layout drawing, and Plate B produced.

For this work the ordinary brown detail paper is very satisfactory. A hard lead pencil is necessary, as hard as 6H, and the point must be kept well sharpened.

Rules of Action. There are two general rules of action in producing a drawing which give the answer to the question which frequently confronts the beginner: "What is to be done first?" or "What is to be done next?" These rules are: (1) Draw everything that is positively known; and (2) work from the inside to the outside.

Every problem has some positive data, assumed or calculated, to start with. The first thing to do in every case is to get this data represented by lines on the paper. An expert designer has been heard to say that until he had spoiled the blankness of his sheet of paper by some lines, he could not design. There is something in this; and almost invariably the first line to draw is a horizontal center line somewhere near the middle of the sheet; draw it! Draw it at once without hesitation, and the layout is begun. We now have something about which to build.

Development of Layout—In this case the designer would first calculate the size of the piston rod, and determine the fastening to the piston. He would then draw the rod and build a hub around it. He would next calculate the width or thickness of piston and size of packing rings, and draw the two vertical lines 5 inches apart, to indicate the piston faces. These lines would be limited by the cylinder bore, which he knows to be 16 inches; hence horizontal lines 16 inches apart, parallel to and symmetrical with the center line, are the next to be drawn. Short vertical lines indicate the location of

the packing rings. As the nominal travel of the piston is to be 12 inches, the location of the piston and rings can be shown on both sides of the central vertical line at the limits of travel. A clearance must exist between the heads and the piston (in this case $\frac{1}{4}$ inch is allowed), hence the lines of the heads can be drawn, and the general inside outline of the cylinder barrel is complete.

This is all in direct application of the foregoing rules, and is so simple, natural, and direct that it hardly requires such explicit statement. We have simply taken such data as we had and put it on paper, placing it where it can be seen from all sides, and where the mind is relieved of the labor of carrying it.

If the student will only appreciate this one rule and draw all he knows about the problem, he is well on his way to its solution. *Draw everything you know, and work for what you don't know* is what these two rules say, and the first question to arise should be: "Have I drawn everything that is known about the problem?" before he asks himself or any one else: "What shall I do next?"

Dimensions in Even Figures. One other rule might be added to these two: *Keep dimensions in even figures, if possible.* This means that small fractions should be avoided. It is just as easy to bear this point in mind, and save the workman much annoyance and chance of error, as it is to disregard this matter. Even figures constitute one of the trade-marks of an expert draftsman. Of course a few small fractions, and sometimes decimals, will be necessary. Remember, however, that fractions must in every case be according to the common scale; that is, in sixteenths, thirty-seconds, sixty-fourths, etc.; never in thirds, fifths, sevenths, or such as do not occur on the common machinist's scale.

A systematic, definite mode of treatment on these lines must become a habit, so that all problems, however complicated, can be approached with confidence in the same way. It is the drawing of one line which makes clear the drawing of the next and subsequent lines; and the most serious obstacle which the student is likely to set for himself is trying to see the whole problem through from the beginning. Even an expert cannot do this, but allows the layout to develop results as he proceeds.

Cylinder Details. The details of the piston and rod being given in Plate C, the foregoing work is very easy for the student. The

thickness of the barrel and heads being determined ($\frac{7}{8}$ inch in this case), the exterior outline may be partially drawn. The fixed head at the yoke end must be thicker than this, in order to receive the yoke and stuffing-box bolts without breaking through. The recesses or counterbores at either end of the cylinder should be so located that the packing rings run over the edge a little at the end of the stroke, thus preventing the wearing of a shoulder by the piston stopping in the same place every time. The counterbore should be deep enough to allow reboring the cylinder without the counterbore being touched by the tool. In this way the counterbore is retained to center the cylinder at its original location.

Port Details. The size of steam ports having been calculated, they may be drawn in, the turns being made easy and as direct as possible. The height to valve seat must be kept at the lowest limit consistent with sufficient metal between and outside of the ports. As the detail of the ports might be somewhat troublesome, it is shown in an enlarged sketch for the student's benefit, Fig. 121. Chipping or filing strips $\frac{1}{8}$ inch high are left on the port edges, which must be true, in order to finish them up easily.

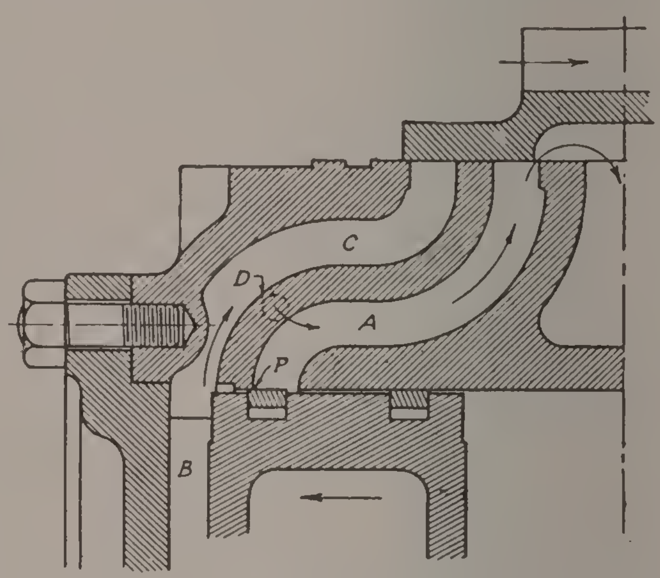


Fig. 121. Enlarged Details of Steam Port

The three inner ports are for exhaust, the outer ones for admission of steam. This five-ported cylinder is peculiar to the direct acting steam pump, it being a device to effect the cushioning of the piston at the end of the stroke, thus preventing the piston from striking the heads. This is necessary, since no positive limit of motion exists, as is the case in machines with crank and connecting rod.

When the edge of the piston has passed the outer edge of the exhaust port, as shown in Fig. 121, the steam, which has been exhausting through port A, is confined in space B and port C, and, being compressed by the piston, acts like a spring to retard its motion. If the point P is properly determined for a given speed, the piston will always compress the steam just enough to cause it

to stop at the end of the nominal stroke; in this case, $\frac{1}{4}$ inch from the head. It is evident, however, that at different speeds the piston will have more or less power to compress the steam, and will not stop at the point desired. This causes the trouble of "short stroke," and consequent inability to make the pump work to its full capacity. Now if we connect ports A and C by a small opening shown dotted at D, and control this opening by a plug valve operated by hand from the outside, we can let a little steam leak by into port A, thus reducing the cushion and allowing full stroke.

In order to avoid complicating the drawing, no cushion valves are shown or required to be put on by the student. They are not customary in small pumps, but might advantageously be put on the present illustration.

The valve seat must be a scraped surface, while the chest face need not be; hence the latter is finished $\frac{1}{8}$ inch lower. This also gives a ledge against which the steam chest fits, thus securing positive location.

Cylinder Heads and Steam Chest. The bolting of the heads and the steam chest should allow a width of packing inside of the bolts of $\frac{1}{2}$ to $\frac{5}{8}$ inch, otherwise there is danger of the steam blowing out the packing and causing leakage around the bolts. The bolts do not fill the holes, the latter being drilled large, from $\frac{1}{16}$ to $\frac{1}{8}$ inch. The spacing, if wider than 5 or 6 inches, is likely to permit springing of the flanges between the bolts, and consequent leakage. Bolts less than $\frac{5}{8}$-inch diameter are not desirable, as they can be easily twisted off with an ordinary wrench. In this case the cylinder head takes $\frac{7}{8}$-inch bolts, the yoke, stuffing-box, and gland, $\frac{3}{4}$-inch.

The flanges of heads and cylinders are usually from 25 per cent to 50 per cent thicker than the body of the casting.

Drips, $\frac{1}{2}$-inch pipe tap, to be fitted with cocks, are necessary at both ends of the cylinder to readily drain the cylinder of water.

Molding Steam Cylinder. The design is often influenced by the way in which the piece is to be cast. It often takes but a slight change of design to save many dollars in pattern making and foundry work. Hence the habit should be formed of always judging the design of a piece from the foundry standpoint. In this case it is evident that the ports and cylinder bore must be cored out, and the most obvious position of molding is to lay the cylinder on its

side, the parting line of the flask being along a vertical plane running lengthwise through the middle of the cylinder. This permits the chest flanges to draw nicely, likewise the ribs on the foot, and allows the thin curving port cores to stand edgewise in the mold.

Another method of molding would be with the valve seat down. This would involve loose pieces for the chest flanges, and setting of cores for the cylinder foot. It would, however, assure sound metal beyond question at the valve seat. Spongy metal at the important wearing surfaces, the valve seat and cylinder bore, is not permissible in any case, and care in molding and good design are necessary for good results.

All corners must be carefully filleted, and chunks of metal must be avoided, especially where several walls or ribs join. The metal must be kept of average uniform thickness, so that the whole casting will cool uniformly.

Machining Steam Cylinder. The boring may be done on a vertical boring mill, the heavy arm carrying the tool being thrust down unsupported into the cylinder, the latter being rotated by the table to which it is clamped. If the horizontal boring machine is used, the hole through the inside head for the stuffing box must be large enough to permit a stiff boring bar to be passed through. This allows a support at each end of the bar, to take the strain of the cut.

The plane surfaces may be finished on a reciprocating planer or a rotary planer. In the latter case it is desirable to keep all lugs or projections back from finished surfaces, in order to permit the large round head which carries the cutters to pass over them without interference.

The drilling of standard machine parts of this character is usually done through jigs, or plates carrying hardened steel bushings laid out to correspond with the holes required, and through which the drill is guided. These plates are located by some fixed line or lug on the casting, and then clamped fast, thus assuring exact duplication and rapid drilling, and avoiding the tedious laying out of the holes. In order to save changing the drill, it is desirable, if possible, to maintain the same size of hole on any given surface. Of course it is not always admissible to do this.

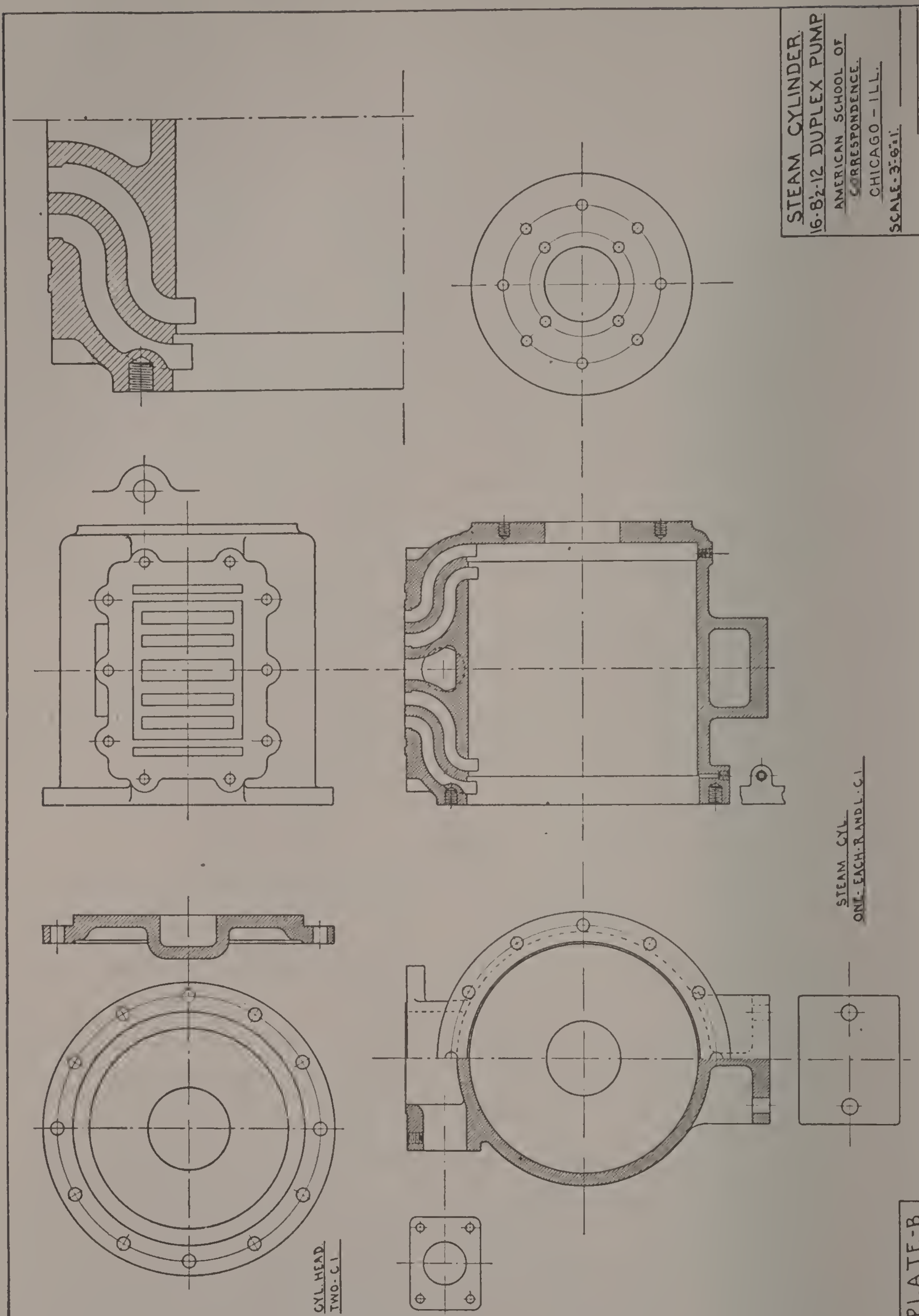
PLATE B. STEAM CYLINDER

After the exact and complete development of the steam-end layout, the student should be pretty thoroughly acquainted with the details of the cylinder. All the work thus far has been entirely for his own information, to get his ideas in visible shape, so that he himself can have a permanent record of them. This layout, however, is not in suitable form to finish up into a detail drawing. Its sketchy nature and the confusion of parts, especially if attempt were made to add dimensions, would render it somewhat difficult to be read by a workman taking it up as an unfamiliar subject. Hence it is now necessary to separately detail the parts, with the object in view of transferring, in the simplest and most direct manner, specific information to the workman which will enable him to construct the several parts. It is not enough now that the drawing be clear to the man who makes it; it must be absolutely clear to the shop mechanic, who has no means of knowing the designer's plans except through the information which the drawing gives on its face.

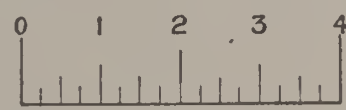
This requires that the draftsman should put himself in the workman's place, and forestall, by the explicit nature of his drawing, all possible questions which may arise in the shop. In this way only can he hope to avoid errors of construction and the continual annoyance of endless explanation of his orders.

Size of Plate. Plate B is to be a finished drawing, and the first thing to do is to lay out the sheet. The standard sheet for details which has been adopted is 18×24 inches trimming size, with $\frac{1}{2}$-inch margin all round, so that the working space is 17×23 inches. The rectangle for the title is to be laid off $2\frac{1}{2} \times 4$ inches in the lower right-hand corner, and must never be altered, either in size or position. This does not mean that other sizes are wrong, but once a standard system is adopted it must be strictly adhered to, both for artistic and commercial reasons. The scale to which the drawing is to be made is indicated in the title corner on every plate.

Scales to be Used. The scales permissible for shop drawings in the United States are those readily derived from the common foot rule, such as full size, 6 inches = 1 foot, 3 inches = 1 foot, $1\frac{1}{2}$ inches = 1 foot. These are the most common, most easily read from an ordinary scale, and one of these can usually be adopted. The student should learn to read these from an ordinary scale without


STEAM CYLINDER.
16·8½·12 DUPLEX PUMP
AMERICAN SCHOOL OF CORRESPONDENCE.
CHICAGO - ILL.
STEAM CYL.
ONE · EACH · R AND L · C.I.
CYL. HEAD
TWO · C.I.
PLATE-B

being confined to a special graduation. To do this it is not necessary to divide each dimension by 2, 4, and 8 to get half size, quarter size, or eighth size, and then lay down the result. For half size, or 6 inches = 1 foot, $\frac{1}{2}$ inch on an ordinary rule represents 1 inch. Hence, each half inch may be read as 1 inch, and its subdivisions accordingly, thus: 

For 3 inches = 1 foot, or quarter size, $\frac{1}{4}$ inch represents 1 inch, and looks thus: 

For $1\frac{1}{2}$ inches = 1 foot, or eighth size, $\frac{1}{8}$ inch represents 1 inch, and looks thus: 

It is very easy to get accustomed to this, and it saves much time and trouble hunting up a special scale every time.

The other allowable scales, less common, but sometimes necessary on large work, are 1 inch = 1 foot, $\frac{3}{4}$ inch = 1 foot, $\frac{1}{2}$ inch = 1 foot, $\frac{3}{8}$ inch = 1 foot, $\frac{1}{4}$ inch = 1 foot, and $\frac{1}{8}$ inch = 1 foot. To use these scales conveniently, special graduation is desirable.

Blocking Out Plate. The general arrangement of the sheet, number of views, and approximate space occupied, should be blocked out first. This can easily be done from the original layout. In general, several cross sections are preferable to a single view, which involves many dotted lines. Dotted lines are very convenient for showing invisible parts of an object, but they are often abused, and the drawing of a complicated piece made indefinite and confused thereby. As already stated, a working shop drawing is solely to convey information to the workman at the least possible cost. A careful consideration of this will settle the question of the number of views necessary, their character, and the amount of dotted line work desirable.

Never let the drawing become the master; always be master of the drawing. Do not draw an extra view if no use can be seen for it. Do not put in dotted lines if the detail is completely shown without them. Full lines, or lines which show visible portions, must, of course, be shown completely.

Practice of Checking Dimensions by Measurements. The nature of the pencil work on Plate B should be the same as on the original layout; viz, sharp, definite lines and positive intersections. Above all things learn the habit of accurate workmanship, for it

will save many errors and a vast amount of time. The draftsman must check himself at every line he draws. Slight errors in scaling will often throw parts out of proper relation to each other, and interferences, which the drawing does not show, will become apparent only when the parts get into the machinist's hands.

It is dangerous practice to project across from one view to the other. It only takes a slight irregularity or spring in the T-square to vary the location of lines very perceptibly from where they should be, and once out of scale from this reason it is almost impossible to work a view with any certainty. Rather than project across from view to view, the principal lines, at least, should be scaled off on each view, and it will be found that in the end time will be saved and greater accuracy secured.

Complete Development of Different Sections. It is not economy of time to finish one view before beginning another. It is better to take some single detail of the drawing and develop it in all views, in order to study it from all sides. What is completed in one view may be found to be totally wrong when developed from another side, and the time spent on the first view will be wholly wasted. For example, in the present case the steam ports should be drawn in side elevation, end elevation, and plan, and when thus completed the mind can leave them and in a similar fashion take up the study of the flanges, then the cylinder foot, and so on. Thus again the draftsman is master of his drawing, for he is continually making it tell him whether he is right or wrong. If, on the contrary, he allows himself to look at but one side at a time, and works from that standpoint alone, it may lead him into many difficulties from which he cannot readily extricate himself.

Do not be afraid to use the eraser. The draftsman who hesitates to draw until he is positive that no change will be necessary, is likely to spend the greater portion of his time in unprofitable dreams, for he is attempting the impossible. A drawing is a means, not an end; and, as has been already pointed out, it greatly assists the draftsman in clearing up many doubtful questions which the imagination alone cannot do.

A bold attack of a problem shows the quickest path to its solution, even if lines must be erased again and again. It is a sign of serious lack of ability to hesitate in the use of pencil and eraser.

Clearness of Drawings an Important Point. Attention is called to the simple, straightforward character of Plate B. Notice the almost entire absence of dotted lines; the enlarged section through the ports, giving ample opportunity for dimensions without confusion; the use of a half end elevation and a half cross section—the one to make clear the flange and bolt layout; the other to show the exhaust opening, the small auxiliary views (drawn at convenient points) of the exhaust flange layout, the cylinder foot, and the drip boss.

A steam cylinder is a fairly complicated casting; and it would be an easy matter, by the use of elaborate views, the dotting in of parts already completely shown, and careless linework, to rob this drawing almost entirely of its clearness and directness of illustration. *Just what is necessary* (for clearness' sake) *and no more* (for cheapness' sake), is the whole matter in a nutshell, and is what determines its shop and commercial value.

Dimensions and Letters. A good line drawing can be spoiled by poorly arranged dimensions and hasty lettering. The five principal points to be kept in mind to develop excellence in this respect are: (1) system; (2) accuracy; (3) clearness; (4) completeness; (5) character.

System. The habit of system in placing figures and letters on a drawing is the one element which, to a large extent, controls all the others. If the systematic habit is established early, the other requirements will be fulfilled more easily. A haphazard method will, on the contrary, just as surely prevent the successful cultivation of the ability to figure a drawing. In fact, if the haphazard habit is continued it will itself, by the dissatisfaction which it causes, soon compel the draftsman to change his occupation.

In the first place, whatever part of a machine detail is to be dimensioned, that particular part should receive attention until it has been completely figured. Do not jump from one point to another, putting in a figure here and another there. Stick to one thing until it is done.

For example, take Plate D and the simple detail of the steam pipe. Suppose we start with one of the square flanges. The first question is: "Where is this flange located?" This is answered by the dimensions 5-inch and 21-inch centers, which refer the face of the flange to the center of the pipe and the flanges to each other.

The next question is: "What are the three dimensions of the flange — length, breadth, and thickness?" This is readily answered as shown on the drawing. The next question is: "What further description is necessary to completely specify the shape of the flange?" This is answered by the radius of the corners, $\frac{3}{4}$ inch R. Next, "What drilling or special feature exists in the flange?" This is answered by $\frac{11}{16}$-inch drill, $3\frac{1}{2}$-inch centers, and the letter *f* to denote that the face is to be finished.

The round flange of this pipe is approached and figured in the same way, except that the location of the face is preferably referred to the face of the square flange by the figure $8\frac{1}{4}$ inches, instead of to the center of the pipe, because the planer hand will more naturally use this figure.

These flanges are now to be connected by a pipe involving two sizes. The main pipe is 3 inches diameter inside, 4 inches outside, and $\frac{1}{2}$ inch thick, running into the two branches by fillets and radii, as figured. The two branches are really one pipe, $2\frac{1}{2}$ inches inside, $3\frac{1}{2}$ inches outside, $\frac{1}{2}$ inch thick, and sweeping down into the square flanges by 4-inch radii.

This systematic method takes longer to explain than to actually execute, but it is typical of the train of thought which must be followed on all pieces, simple or complicated, in order to properly place dimensions.

In general, it may be stated that all parts of a piece must be referred either to each other, or to some common reference line, or to both. Each part so referred must then be figured as a piece by itself, and then its connections to the principal structure. Thus, figuring a machine detail involves three things: (1) relative location of its parts; (2) proportions of these parts; (3) proportions of connecting members.

As in the original design of a piece, so in the figuring of it the draftsman must as far as possible put himself in the place of the workman, judging the methods and processes of construction and available tools. This will largely influence the arrangement of the dimensions. Of course it implies considerable experience in shop work, which some students do not possess. He can begin none too early, however, to learn to look at his work from the shop standpoint, and surely make it some better on that account.

Pieces must not only be systematically dimensioned, but regularly specified and called for by suitable titles.

A title should specify at least three things: (1) name of piece; (2) number wanted for one machine; (3) material.

To these might be added a fourth; viz, pattern or piece number. The latter is not specified on the drawings under discussion, because systems of pattern and piece numbering are so varied that little would be gained by developing one for this special study.

These titles should always be put on in the same way, as the workmen become used to a certain system and are likely to misunderstand directions if a regular plan is not followed. A good way to arrange titles is suggested on the plates, although there are others which might be used.

Bolts are usually specified by diameter and length under the head, the length of thread being determined by some standard system in use by the shop, unless otherwise called for. Bolts are specified on the sheet containing the piece into which they are tapped. In the case of through bolts, tapped into neither piece, they are preferably called for in connection with the principal member.

Accuracy. Of course the dimensions on a drawing must be accurate. It is, however, a very easy matter to make errors. To insure accuracy a figure must *never* be put down carelessly, and a constant watch must be kept that scaled figures add up to over-all dimensions. It will not do to rely upon scaling alone, as a very slight variation from exact scale may throw two dimensions out with each other. In spite of all the care that can be exercised errors will creep in, and a final thorough checking must be given a drawing before it is pronounced complete. A good rule to follow in checking up is to "assume everything wrong until it is proved to be right."

Clearness. As in the line drawing itself, there must be absolute clearness of instruction by the dimensions. Any doubt as to what a figure is, or what it means, rules out that figure as part of the drawing. If a piece is made wrong because doubt of this character is transmitted to the workman, the draftsman is always held responsible for the error.

Figures should, in all cases, be placed where they can be most clearly read. They should be bunched on a single view as far as possible, but not when greater clearness demands that another view

be used. It hinders the reading of a drawing materially if the eye is forced to jump over large spaces of the sheet from view to view, to catch the several dimensions of a small detail. Usually it is easy to so group figures as to avoid this.

It is a good plan to keep dimensions off the body of the drawing, when it can be done so conveniently. It is not worth while, however, to go out of one's way to do this, as figures in the open spaces of a detail do not at all destroy its clearness.

Extended notes on a drawing to make it clear should not be required, but they should be used without hesitation if any doubt exists. An explicit note of instruction is the final resource for clearness when the art of drawing fails of its purpose, as it sometimes does.

Completeness. A detail is completely dimensioned when it shows *all* the figures necessary for the workman. Anything short of this is incompleteness. As modern shops hold the draftsman solely responsible for the design, the mechanic is not allowed to modify it by filling in any omitted dimensions. The only way to be sure that all the dimensions are on is to systematically go all around a piece inside and out, according to the method suggested under the paragraph on "System".

It is a good plan to always bear in mind that not only the machinist is to use the drawing, but also the pattern maker. For the benefit of the latter, special attention is desirable in figuring the cores. This saves him some addition and subtraction. In general, it has been found that less chance of error exists if mathematical work is not required of the shopman, all necessary data being furnished on the face of the drawing.

Character. By character in figures and letters is meant uniform style, height, and slope, and a certain boldness peculiar to the work of the expert draftsman. The last is difficult for the novice to acquire. The student should not be discouraged because his efforts do not look like impressions from printers' type. Artistic excellence is the result of long experience, but is based on character. If the student can once get character into his work, the artistic feature will, with careful and constant practice, gradually develop. It is safe to say that there is no one element of a drawing which more positively stamps it as the work of an amateur than the char-

acter of the lettering, and every attention should be paid to getting out of the apprenticeship stage in this respect. Freehand lettering only is permitted in the drawings illustrated herewith. Ruled letters are seldom found on any working drawings, as the element of time involved is so great that few shops are willing to pay for it.

Uniform style requires that if capitals only are used in titles, they only must be used in notes and elsewhere on the drawing. If lower-case letters are used, they must be used in every part of the drawing. One style should not be mixed with another. The height of the letters should be limited by two horizontal lines, and though practice may render the upper line unnecessary, it takes but an instant to draw it, and uniform height is then assured. A good height for titles of details such as are illustrated is $\frac{7}{32}$ inch. The height once chosen should be adhered to throughout the whole set. A medium, not a hard, grade of pencil (3H) will give the hand greater freedom. A great temptation exists to omit titles from the pencil drawing, simply inking them on the tracing. This is false economy of time, for in the end it will be found that enough time will be saved by the certainty with which the tracing can be made to more than pay for the labor on the pencil drawing. Again, it permits the tracing, in regular shop practice, to be made by cheaper labor than that which produced the pencil drawing.

Uniform slope is most easily acquired by the use of guide lines put in at frequent intervals. A small wooden triangle can be made, giving the required angle. The angle of the letters shown on the plates is 9 degrees, or about 1-inch slope in 6 inches. The question as to whether letters should incline backwards, forwards, or stand vertical, does not enter this discussion. Character is not affected by the slope. The student may choose whatever comes most natural to him, but having chosen, the character of his work will be spoiled if he varies it. The most difficult of the three is the vertical style; hence most draftsmen incline their letters. The backward slope is used on the plates of this shop drawing paper, thus giving the student opportunity to compare with plates in the earlier books, and follow his preference.

The effect of change of style, height, and slope is shown in Fig. 122. Attention is called to Fig. 123, which is a sample title, in which these points are corrected.

Principal Titles. The principle title of a drawing should contain at least seven items: (1) name of principal details shown; (2) name of machine; (3) firm name and location; (4) scale of drawing; (5) date of completion; (6) draftsman's signature; (7) filing number.

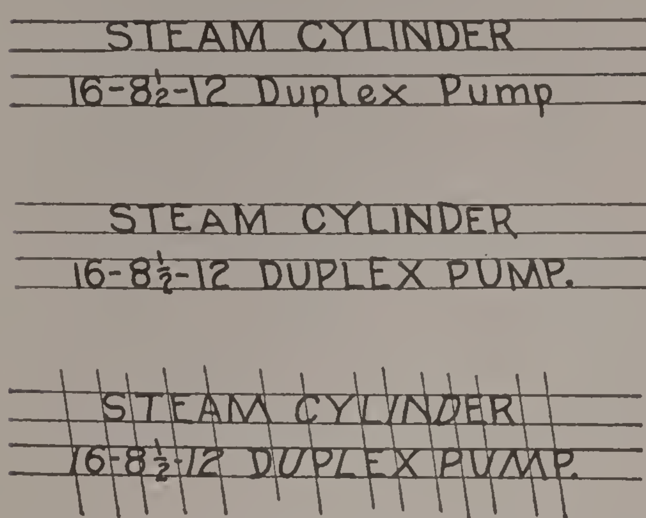


Fig. 122. Sample Titles Showing Effect of Non-Uniformity of Lettering

To these are often added others, but for purposes of filing and reference the above at least *must* be put on. The filing number may or may not be put in the title frame, but it is really a part of it. It is often put in the margin below the title.

An arrangement of title should be established and then followed exactly, without variation either as to location on sheet or detail make-up. Abbreviated words are always permissible in titles, provided the meaning is clear. Special care must be taken in punctuation, however, as a title, whether abbreviated or not, has an unfinished appearance if the periods, commas, and other necessary punctuation marks are not included.

The sample title illustrated in Fig. 123 indicates the arrangement chosen for the drawings of Part I. Note that in this special

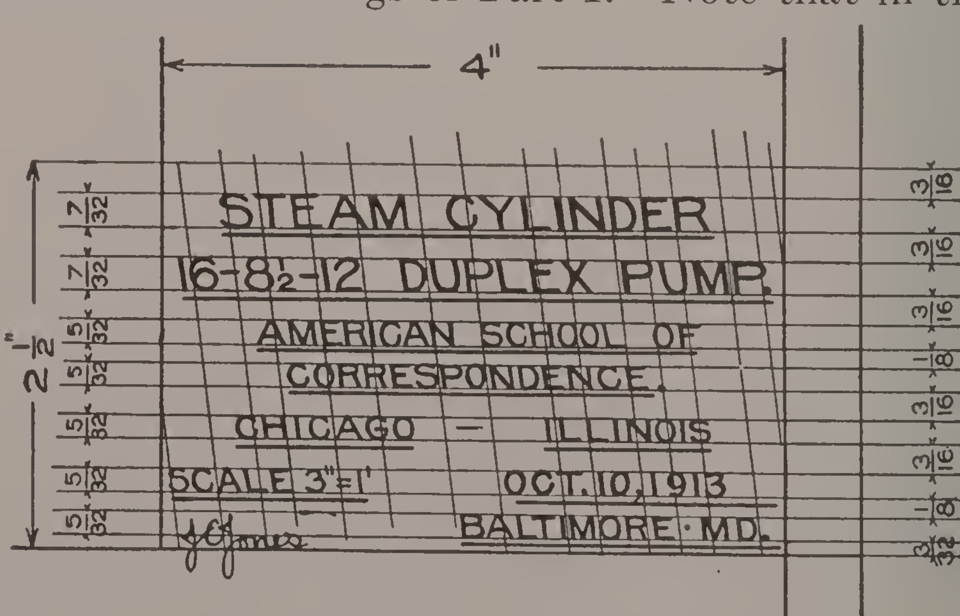


Fig. 123. Sample Plate Title Properly Drawn

case the residence of the student draftsman has been substituted for the file number of the drawing.

This style of title must be put with care on every drawing,

even on the rough pencil layouts. In the latter case it may of course be left in pencil, as the rough layouts are not to be inked.

Inking and Tracing. Both bond paper and tracing cloth are used in business practice for finished drawings. It is desirable to keep a stock of both in any drawing office, so that either may be used as occasion requires. Bond paper stretched on the board gives a beautiful surface to take the ink, and very handsome and effective detail or assembled drawings can thus be produced.

Changes are not quite as readily made on bond paper as on tracing cloth, and it takes a little longer to make the blue print. In other ways the bond paper is not quite as flexible to use as the tracing cloth. However, one must be guided entirely by shop conditions to settle the question of preference. As the tracing cloth is generally used, and suits the purpose of the student better, it will be required in this work.

Preliminaries. The inking should be done on the *rough* side of the cloth. One reason for choosing this side is that as the cloth tends to curl under toward the glazed side, the drawing as it lies right side up will tend to straighten itself. This seems to be a small point, but it is a very important advantage for filing and for the convenience of those who are to handle the drawings. Also the rough side takes colors and inks better than the glazed side. To trace on the glazed side is not wrong, for it is often done, but it possesses no advantages of its own, and has the disadvantage mentioned above.

Chalk dust scattered over the surface of the cloth after it is tacked down will remove the slightly greasy coating which prevents the ink from flowing well from the pen. This is always necessary if the glazed side be used, and usually for the rough side. The chalk must be carefully removed from the cloth before inking.

Rules for Inking. The first step in inking is to draw the center lines. Remember that *accurate intersections* are of the utmost importance. No circle is complete without two intersecting lines, preferably at 90 degrees, to determine its center, and these lines should be inked before the circle. When this is done, a definite point exists for the needle point of the compasses. If the circle is drawn first, the needle point may not be placed accurately at the center on the pencil drawing beneath, thus throwing the location out.

Likewise the principal center lines of pieces, the lines around which the pencil drawing was built up, should be at once put in.

The main body of the drawing, the full lines, should be taken next. In general, circles and arcs should be inked first, but there are cases where it is easier to run the arcs into the straight lines than to match the straight lines to the arcs. These are exceptions, however, and can be judged only as the case arises.

Straight lines, horizontal and vertical, should be inked with the T-square and triangle *in position.* It is a common practice to dispense with the use of the T-square entirely in inking in, using the triangle to match the lines to the arcs already drawn. A necessity for this implies very poor work on the arcs, for with any reasonable care true horizontal and vertical lines will match the arcs all right. With regard to time required, the accuracy with which the T-square may be brought up to a line, or the triangle set on the T-square, more than makes up for the time gained in even an approximate setting of the triangle without a guide. It is just as easy to cultivate the habit of holding the T-square and triangle with the left hand and the pen with the right, and draw an exact line, as to lapse into the other method, which is not workmanlike.

The lines of the body of the drawing depend for their width upon the size of the detail. For a large piece they may be $\frac{1}{32}$ inch wide, and the shade lines $\frac{3}{64}$ inch. For a small detail such widths would be too great. Remember that *contrast* is the principal aim, and to produce it is the only reason why we use different kinds of lines on a drawing. Hence the greatest care must be exercised to prevent body lines from becoming confused with center or dimension lines, and *vice versa.* Also thick lines are desirable for the production of a bold blue print.

Shade Lines. Shade lines certainly improve the drawing from an artistic standpoint, and the student has been shown in Machine Drawing, Part I, how to put them on when desired. Whether or not it is desirable to adopt them on all working drawings is not the purpose of this book to decide, or even discuss. Almost always drawings can be made perfectly clear without them, and are so made and satisfactorily used in probably the majority of shops. Some shops are willing to pay for the extra time necessary to put on shade lines; this, however, is purely their own investment.

Crosshatching. Cross-section lines are usually drawn at an angle of 45 degrees with the horizontal, and on sections which are adjacent to each other the slope should be in different directions. If three or more sections come together, the width between section lines can be so changed as to indicate clearly the different parts. An example of this is shown in Fig. 124.

The spacing of section lines must not be too fine, rarely closer than $\frac{1}{16}$ inch, more often from $\frac{3}{32}$ to $\frac{1}{8}$ inch, else the labor involved is too great and uniformity practically impossible. It is a waste of time to rule in section lines on the pencil drawing; they may be sketched in freehand, as shown on the original layout of the steam cylinder. Even spacing concerns the tracing alone, and the student should train his eye to regularity as he traces. The thickness of section lines may be intermediate between that of center lines and the body lines of the drawing.

Inking Dimensions and Letters. Extension lines may be dotted, as explained in Mechanical Drawing, Part III, or they may be fine, full lines, the latter method being illustrated in the series of pump plates in this paper. Dimension lines are also often made fine, full lines. If these lines are made full they should be made as fine as it is possible to draw them and still have them firm, clear lines. The same width should be used as for center lines.

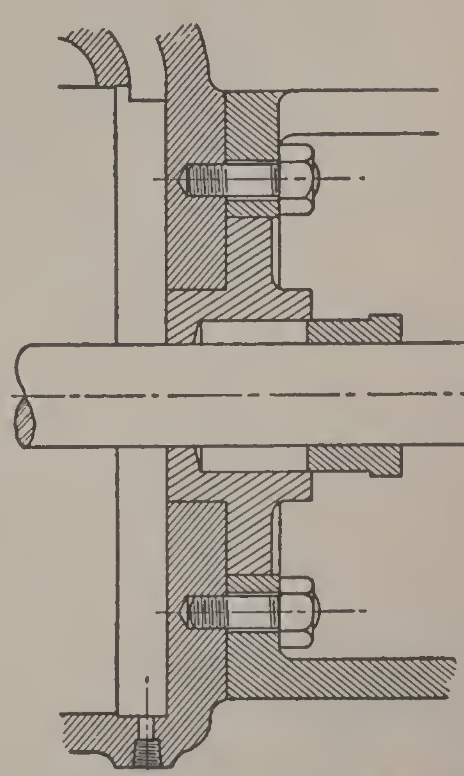


Fig. 124. Section Showing Variations in Crosshatching

Character in inked figures and letters is more difficult to attain than in pencil work. In the first place a pen suitable to the style of drawing is necessary. A civil engineer's fine mapping pen, which gives character to his drawing, is not desirable in producing the bold character of a machine drawing. For the latter, choose a rather stiff, blunt pen which is not "scratchy," but runs smoothly, making a line of uniform width. A pen with a round, or ball-shaped nib, now on the market, answers the purpose well for ordinary details. A bold, free stroke should be made with the idea of producing a smooth, even line, finished at the first trial. The

hesitating uncertainty of the beginner's hand produces a "shaky" letter, and going over a letter or figure twice or more to smooth it up usually makes it worse.

Figures and letters which are broad in proportion to height are easier to make, and have more character. It should never for a moment be forgotten that uniform *height* and *slope* carefully followed will develop character and quickly lead to artistic excellence.

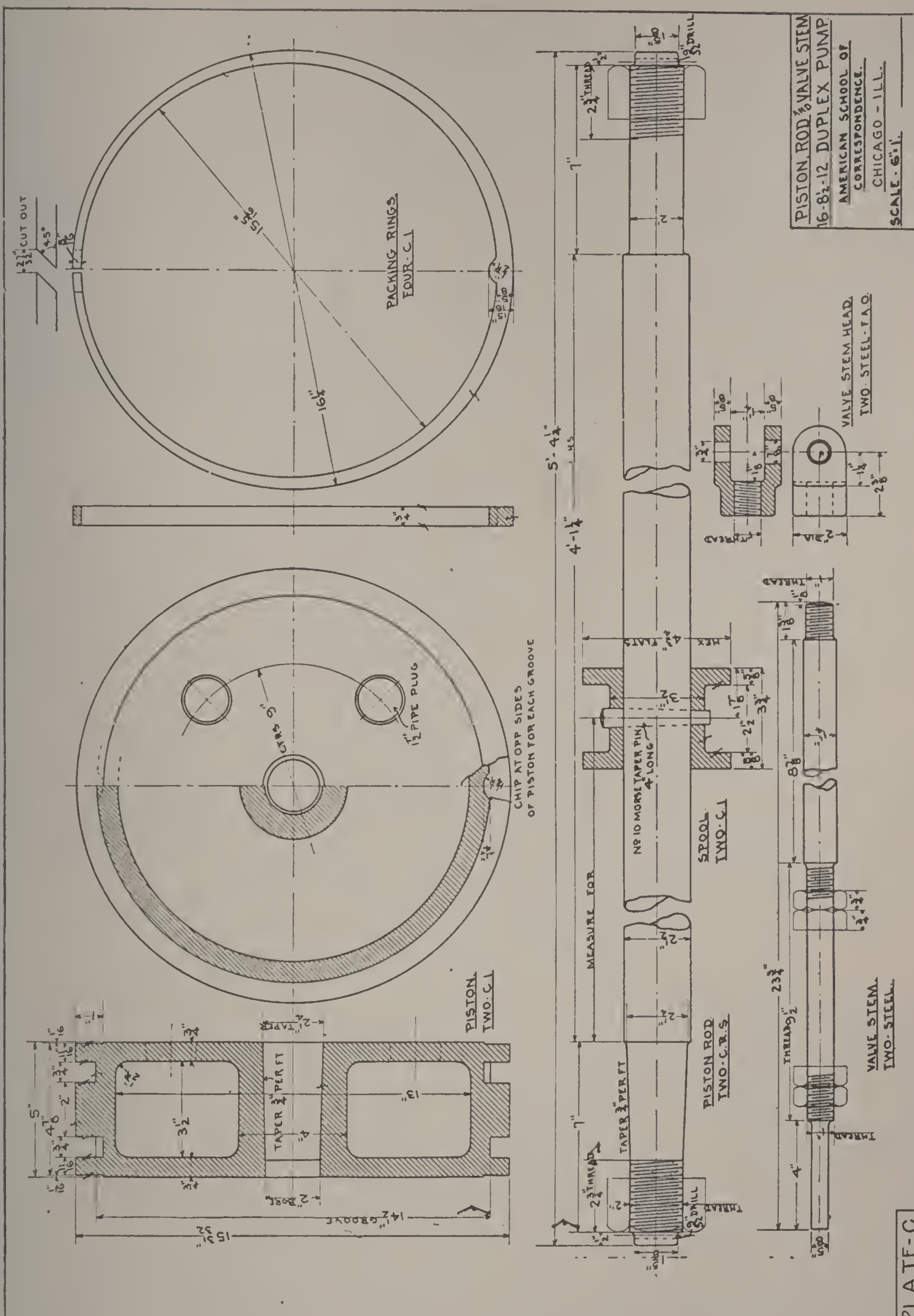
Foot and inch marks are often put after figures according to the common usage. In cases where feet and inches are expressed, thus: 3′-6″, or 4′-0″, they are, of course, absolutely necessary, and the dash between the figures must be very positively indicated. In cases of inch dimensions alone the marks may be put on if desired, but where there can be no doubt that inches, and not feet, are meant, the inch marks are not necessary.

Abbreviations. A list of the most common abbreviations in use on working drawings follows. This list has been adopted for the plates in Machine Drawing Part I:

F. A. O.	finished all over.
f	finished surface.
R.	radius.
D.	diameter.
R. H.	right hand.
L. H.	left hand.
P. R.	piston rod.
P. TAP	pipe tap.
CTRS.	centers.
C. I.	cast iron.
S. C.	steel casting.
Bz.	bronze.
C. R. S.	cold rolled steel.
T. S.	tool steel.
O. H. S.	open hearth steel.
W. I.	wrought iron.

PLATE C. PISTON ROD AND VALVE STEM

Specifications. The piston is of the one-piece box type, with sprung-in rings. The width is reduced to $4\frac{7}{8}$ inches at the outside, so that if the piston strikes the cylinder heads it will not tend to spring and break off the narrow ridge of metal outside of the packing ring. The piston rod is fastened to the piston on a taper drawn in


PISTON ROD & VALVE STEM
16-8½-12 DUPLEX PUMP
AMERICAN SCHOOL OF CORRESPONDENCE.
CHICAGO - ILL.
SCALE 6"-1'.
PACKING RINGS
FOUR-C.I
PISTON
TWO-C.I
CHIP AT OPP SIDES OF PISTON FOR EACH GROOVE
1½" PIPE PLUG
SPOOL
TWO-C.I
No 10 MORSE TAPER PIN 4" LONG
MEASURE FOR
PISTON ROD
TWO-C.R.S
VALVE STEM HEAD
TWO-STEEL-F.A.O.
VALVE STEM
TWO-STEEL
PLATE-C

by a nut, and the nut is checked by a $\frac{1}{4}$-inch split pin. The packing rings are prevented from slipping round the piston by lugs fitting loosely in chipped recesses in the groove. These being at opposite sides for each groove, the leakage of steam through the split in the ring is minimized, for it must pass halfway around the piston before it can pass through the split in the other ring. This is a simple, but fairly effective, device.

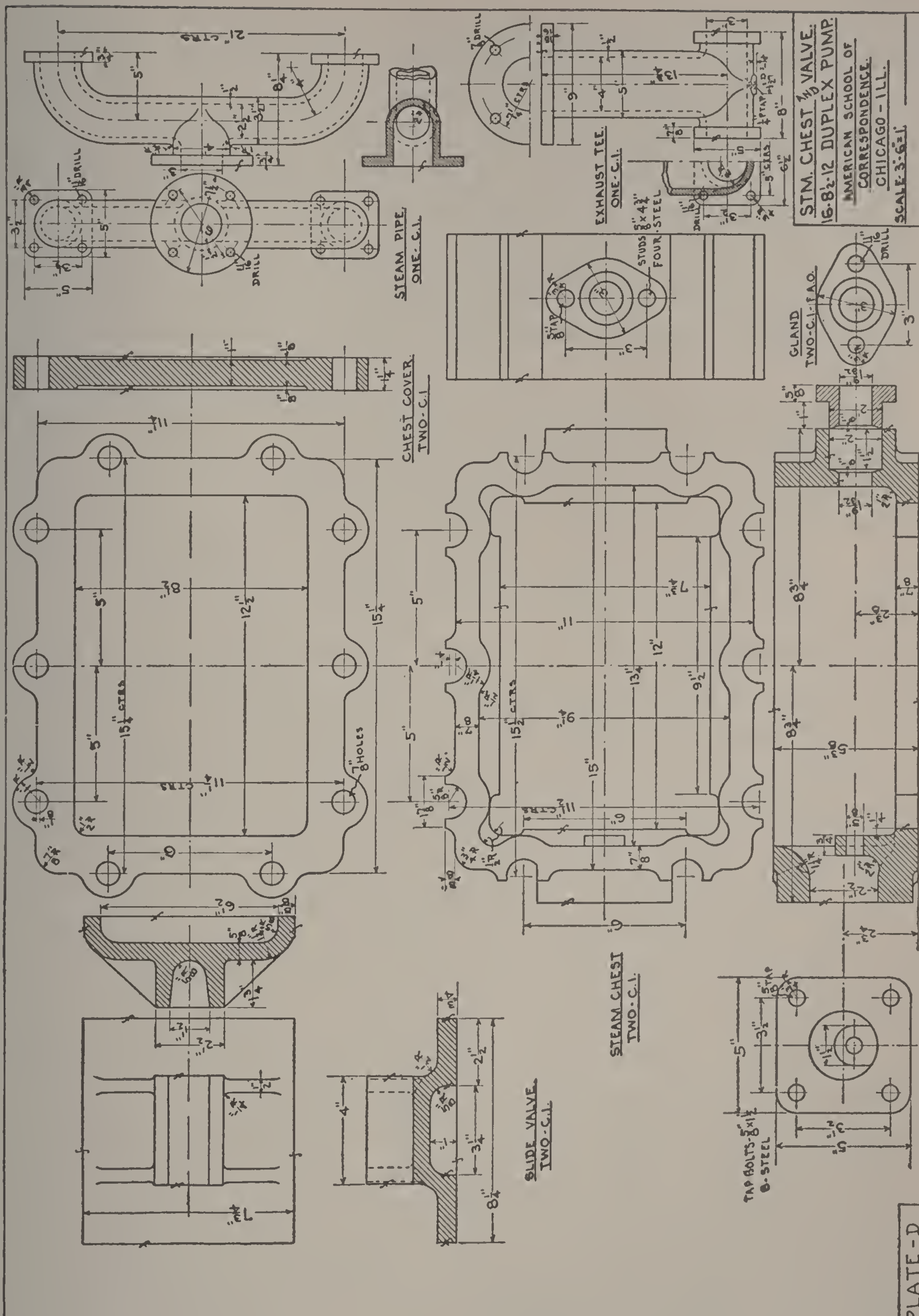
The packing rings are usually cast in the form of a cylinder of some length, turned to a diameter a little larger than the cylinder bore, cut off to the required width, and sufficient space cut out to permit being sprung in to the size of cylinder bore.

The location of the spool on the piston rod is not positively known, as the setting of the valve bracket may be slightly different from what the drawing calls for. Hence, instead of a dimension, the words "measure for" are put on, to indicate that the spool be located during the erection of the pump. The hexagonal flanges of the spool are convenient to hold the rod from turning while screwing on the piston and plunger nuts.

Molding and Machining. There are no special features connected with the molding and machining of parts on Plate C. The holes in the piston side walls are necessary to give supports for the core, the piston being cast on its side. These holes, after the core is cleaned out through them, are plugged as indicated.

PLATE D. STEAM CHEST AND VALVE

Specifications. The steam chest in this instance is located on the cylinder by fitting down over the ledge made by the valve seat. The side flanges also serve the purpose of guiding the valve. It will be noticed that the steam-chest cover is $15\frac{1}{4}$ inches $\times$ $11\frac{1}{4}$ inches, while the steam chest is 15 inches $\times$ 11 inches. This allows a ledge of $\frac{1}{8}$ inch, all around which the cover overhangs the walls of the chest. The steam cylinder flange in order to correspond must likewise be $15\frac{1}{4}$ inches $\times$ $11\frac{1}{4}$ inches. The reason this is done is because of the difficulty of making good matched joints between the cylinder flange, chest, and cover. The practice of thus leaving a little ledge all around is by no means universal, and often the irregularity in the joints is smoothed off by chipping. This is the case with the other flanges on this pump. The steam chest, however, was thought less


STM. CHEST & VALVE
16·8½·12 DUPLEX PUMP
AMERICAN SCHOOL OF
CORRESPONDENCE
CHICAGO - ILL.
STEAM PIPE
ONE-C.I.
EXHAUST TEE
ONE-C.I.
CHEST COVER
TWO-C.I.
GLAND
TWO-C.I.-F.A.O.
STEAM CHEST
TWO-C.I.
SLIDE VALVE
TWO-C.I.
PLATE - D

likely to match properly, and the slight overhang gives the finished appearance of a sort of beaded edge.

The valve is what is known as a "square" slide valve. This means that when the valve is placed central on the ports its working edges are "square" with the ports; that is, in exact line with them. If the valve be moved either way from this position, the slightest travel will admit steam to one end of the cylinder and exhaust it from the other. (See Plate A.) Another way of stating this is to say that a "square" slide valve is a slide valve without "lap".

The valve is driven from the valve stem by the striking of the nuts against the lug on its top. Since the valve is already guided on its edges by the steam-chest flange, the valve stem, to avoid springing, must be perfectly free in the slot cast for it, as is shown by the $\frac{5}{8}$-inch radius of the bottom, the stem being 1 inch in diameter.

The steam-pipe flange is made square to keep the height of the chest as low as possible. The radius of the bend should be ample; in this case 4 inches is considered sufficient.

The exhaust tee must have its upper flange high enough so that the chest cover can be lifted and slipped off the studs without interfering with it. The lower flanges should be made wide enough to permit the tap bolts to be put in without striking the 4-inch vertical pipe, 5-inch centers being necessary. The $\frac{1}{4}$-inch drip-cock, as located, readily drains the steam chest and exhaust passage of both cylinders, as well as the exhaust tee.

Molding. It is evident that the steam chest will be molded in the position shown on the drawing. The parting line of the mold will be through the centers of the steam-pipe opening and the stuffing-box. These holes must be cored out. The main body of the chest could be made to leave its own core, but it may not be made in this way. It may be cheaper to fashion the pattern solid, and make one large core-box for the inside. In this way the pattern will probably hold its shape better and require less repairs, than if it were made in green sand. The core-box will be an extra piece to make, but it probably will cost no more than to carve out the inside of the pattern, and is a rather more substantial job when done. The molding can be satisfactorily done by either

method, shop conditions being the controlling element. As far as the labor of molding alone is concerned, the first method is probably easier, as it saves handling large cores.

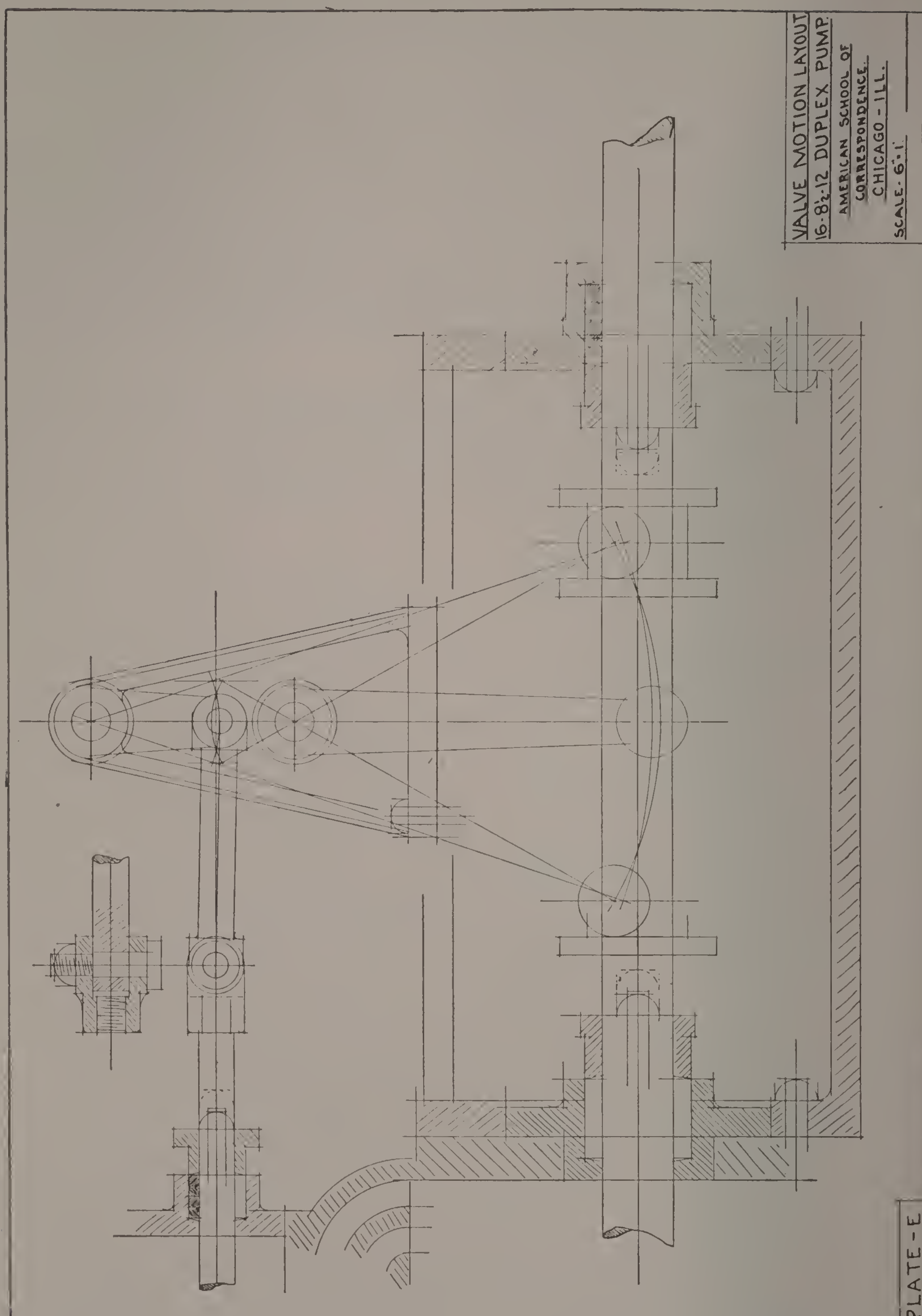
The other parts in Plate D are very simple in their molding, and require no special attention.

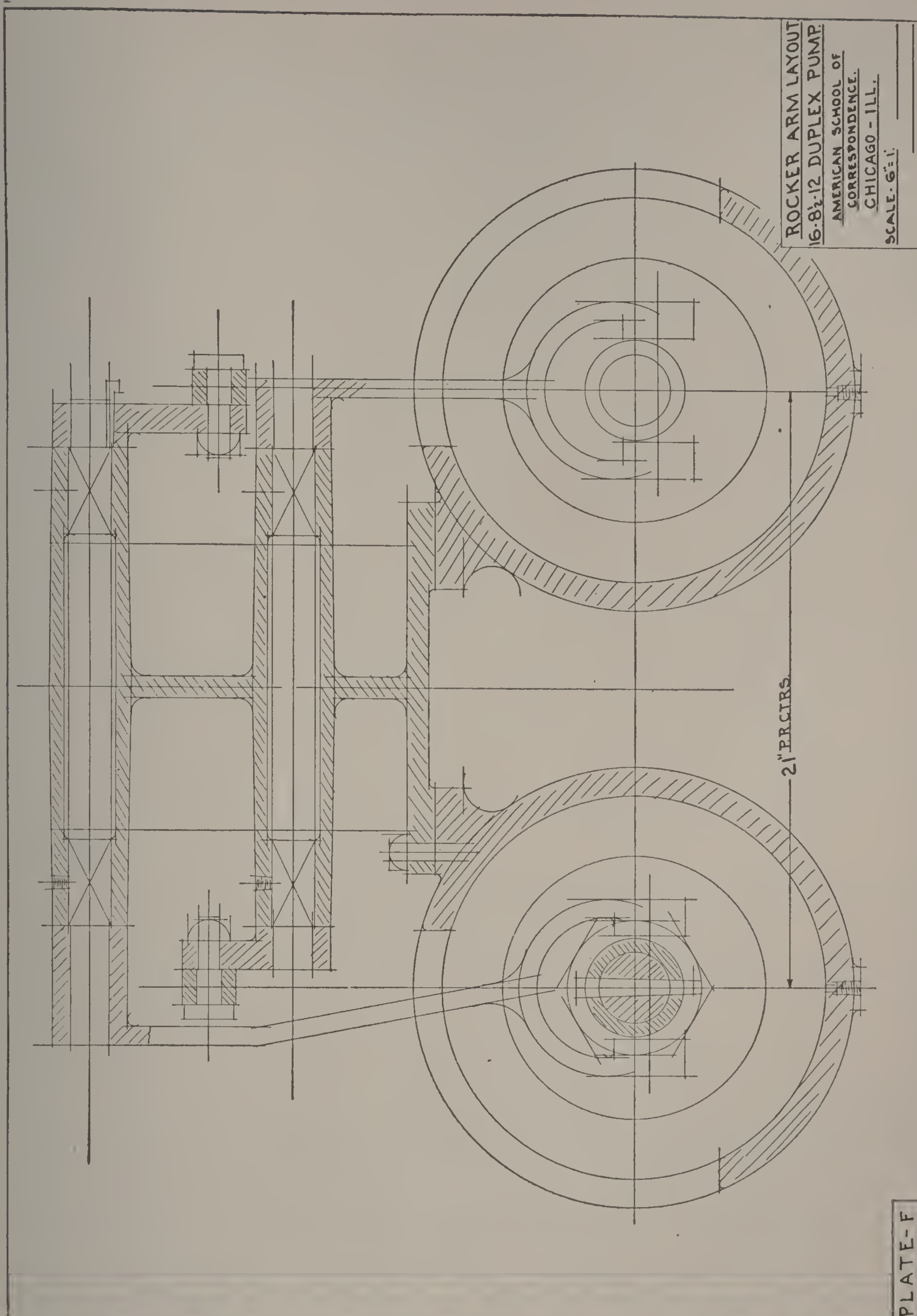
Machining. Most of the surface work on this plate is adapted to the planer. The slide valve may, perhaps, if finished in lots of considerable number, be more satisfactorily handled on the milling machine. The final finish of the face of the valve must be a scraped fit to its seat.

The drilling of the cover and pipe flanges is to actual layout on the casting, or preferably, through jig plates. A templet for laying out is at least desirable, even though the expense of a jig plate be not deemed necessary.

PLATES E AND F. VALVE MOTION LAYOUT

General Specifications. These plates represent the layout of the valve motion, and are necessary in order to find the length of the levers and rocker arms. It will be noticed in Plate F that the valve stem of one side of the pump is controlled by the movement of the piston rod of the other side, the proper direction of motion being given to the valve by placing the rocker shaft above or below the valve stem as required. By reference to Plate A it will be further noticed that the nuts on the valve stem inside the chest, which abut against the faces of the lug on the valve, do not rest against the faces of the lug in the position shown, but have considerable lost motion. This lost motion is one of the essential features of the valve motion of a duplex pump, and permits the valve to remain at rest for a short period at the end of the stroke, though the valve stem may have reversed its motion and begun its return stroke. When this lost motion is taken up by the movement of the stem and the nuts abut against the lug on the valve, the valve will move, and from this point to the end of the stroke be positively controlled by the motion of the stem. At the end of the stroke the stem will reverse, when the lost motion will again permit the valve to rest for the same period as at the other end, and then move on as before. The time of rest of the valve, and consequently the pistons and plungers, is approximately one-third the period of the stroke. This


VALVE MOTION LAYOUT
16·8½·12 DUPLEX PUMP.
AMERICAN SCHOOL OF
CORRESPONDENCE.
CHICAGO - ILL.
SCALE - 6"=1'
PLATE - E


ROCKER ARM LAYOUT
16·8½·12 DUPLEX PUMP
AMERICAN SCHOOL OF
CORRESPONDENCE.
CHICAGO - ILL.
SCALE · 6" = 1'.
21" P.R.CTRS
PLATE-F

means that the piston on one side travels one-third of its stroke before it picks up, through the valve levers, the valve on the other side. During the second third of its travel it is bringing the valve to the point of opening. During the last third of its travel it is opening the port, wider and wider, to steam. Thus the opposite piston will start when the first piston has covered two-thirds of its stroke, and there will be only one-third of the stroke when both pistons are moving at the same time.

This relative period of rest to motion is not always made in this exact ratio, but is at least approximate to it. The period of rest at the end of the stroke is to allow the water end to adjust itself quietly to the reversal of motion about to take place at the end of the stroke. When the plunger stops, the water valves must be given time to seat themselves, and the flow of water through the passages checked. It is much easier to start the flow in the opposite direction if the reversal of plunger motion is not instantaneous. Hence for handling long columns of water, which, once in motion, tend by considerable energy to remain in motion, the duplex pump by this peculiar delayed action has been found to be well suited.

Travel of Valve Stem. It will be found that for complete uncovering of port, and motion divisible into thirds as described, the travel of the valve stem should be three times the width of port, or $3 \times \frac{7}{8} = 2\frac{5}{8}$ inches. A little more than this is allowed, and the travel made $2\frac{7}{8}$ inches in this case. Referring to Plate E, this distance is laid off as shown by the two limiting vertical lines across the line of the valve stem, the central vertical line of mid-position being drawn. The problem then is to find such centers for the rocker arms that the travel of the piston-rod spool will, through proper leverage, produce travel of the valve stem between these two vertical lines. This can readily be done by a few trials, the only requirement for this case being that the extremes of the arc of swing of both piston-rod lever and rocker arm shall be equally above and below the center of piston rod and valve stem, respectively. The greatest possible travel of the piston-rod spool, $12\frac{1}{2}$ inches, is usually laid out in this case, not the nominal 12 inches.

Length of Levers and Arms. From this layout the lengths of the levers and arms may be scaled off for the detail drawing, also the

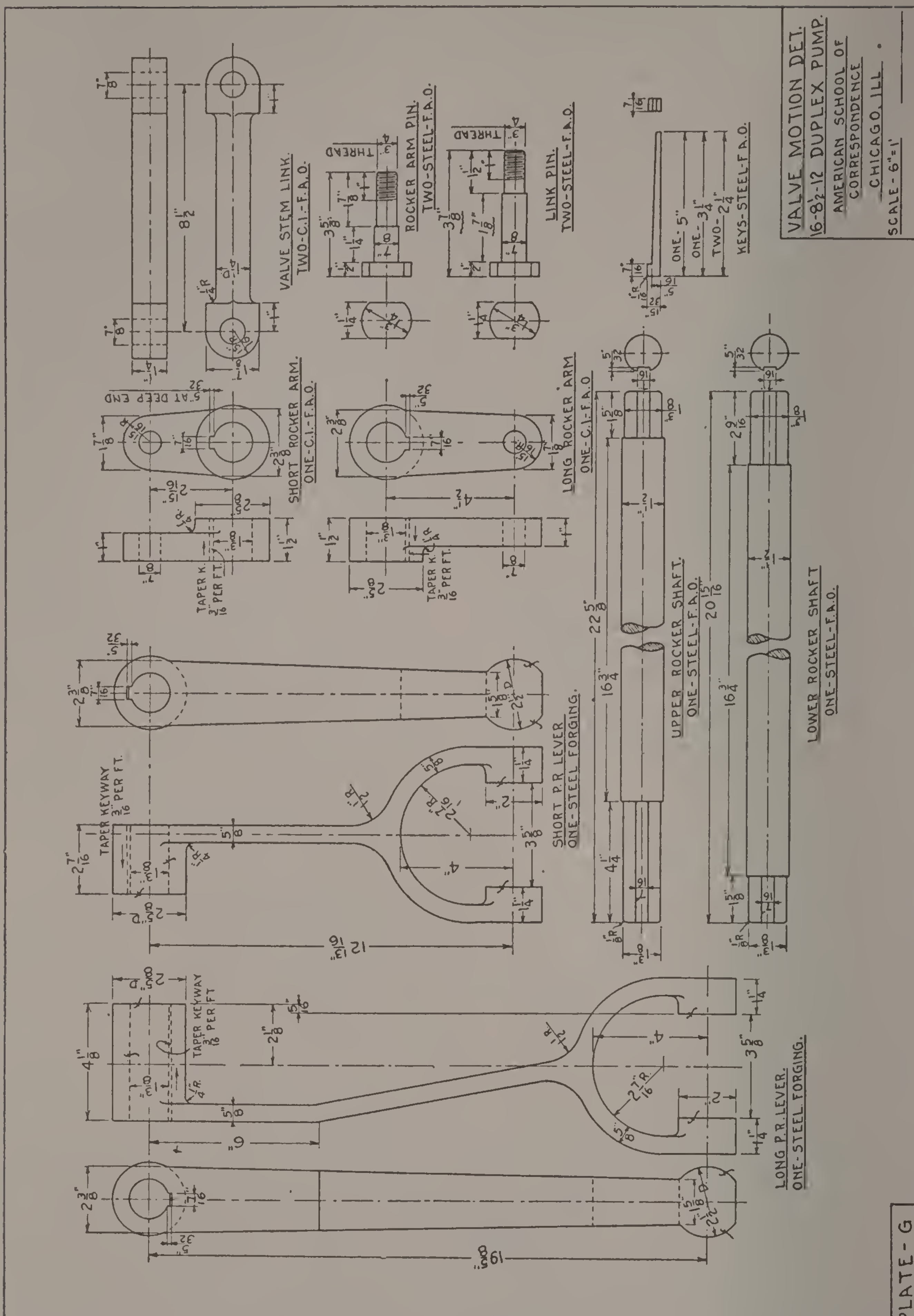
location of the rocker-arm centers. The student has the former given him on Plate G, but the latter, which is necessary for the development of Plate H, must be determined by his own layout. Plate F must also be laid out before developing the cross section of the valve bracket.

Stuffing Boxes. The design of stuffing boxes for both steam and water ends, and the length of the yoke, should be determined next. A safe method of assuming clearance between the spool and the gland studs at the end of the stroke is to imagine that the gland stud nuts have accidentally worked off the studs, so that they are about to drop. They are thus shown by dotted lines on Plate E. A good clearance, say $\frac{1}{4}$ inch to $\frac{1}{2}$ inch, is then allowed, and the gland drawn in. The length of the gland is determined by the number of rings of packing necessary in the stuffing box; it is usually provided that the gland may compress the packing to about one-half its original depth before bringing up against the face of the box. Packing $\frac{5}{8}$-inch square will do for this size of piston rod, hence the faces of the yoke are easily determined, and its detail, with the stuffing boxes, proceeded with as on Plate H. The length of yoke may be brought to an even figure; and proceeding on the above plan the length can be conveniently made in even inches without any fractions; viz, 28 inches.

It will be noticed that the stuffing-box flanges serve to center the yoke in line with the steam and water cylinders. This is a desirable feature of construction, and forms a simple and easy method for lining up the steam and water ends.

PLATE G. VALVE MOTION DETAILS

Piston-Rod Levers. The piston-rod levers on this plate are specified to be steel forgings. Forgings of this kind are expensive, but are light, neat, and reliable for the important service which they have to perform. Castings, whether steel or iron, are much cheaper, and perhaps more commonly used for this detail. When sound they are equally serviceable, though of more clumsy proportions; but the danger in castings of this form is the existence of hidden flaws or pockets, which frequently occur at the points where the hub or the fork joins the arm. These flaws cannot be readily detected from the outside, and breakage may occur at some


VALVE MOTION DET.
16-8½-12 DUPLEX PUMP.
AMERICAN SCHOOL OF CORRESPONDENCE
CHICAGO, ILL.
SCALE - 6"=1'
VALVE STEM LINK. TWO-C.I.-F.A.O.
ROCKER ARM PIN. TWO-STEEL-F.A.O.
LINK PIN. TWO-STEEL-F.A.O.
KEYS-STEEL-F.A.O.
SHORT ROCKER ARM. ONE-C.I.-F.A.O.
LONG ROCKER ARM. ONE-C.I.-F.A.O.
UPPER ROCKER SHAFT. ONE-STEEL-F.A.O.
LOWER ROCKER SHAFT. ONE-STEEL-F.A.O.
SHORT P.R. LEVER. ONE-STEEL FORGING.
LONG P.R. LEVER. ONE-STEEL FORGING.
TAPER KEYWAY 3/16" PER FT.
PLATE - G

critical time, when the disability of the pump may be a serious matter.

Dimensions "Out of Scale". It will be noticed that on the detail of the "link pin" two of the dimensions have a short "wavy" line beneath the figures. This is one of the several ways of indicating that the dimension is "out of scale". Some draftsmen use a straight dash beneath the figure; some draw a circle about it; some print after the figure, "out of scale". Although workmen are not allowed to scale drawings, but are required to "work to figures only," yet for general safety's sake, and for the sake of the draftsmen who consult the drawings frequently, attention must be called to any variation of the figure from the measured distance on the drawing. Nothing makes a workman, or any one else who reads a shop drawing, lose confidence in it more quickly than to discover that it does not "scale"; but when no indication exists that the draftsman himself is aware of it, then every dimension is viewed with doubt and hesitation, and the drawing becomes practically worthless.

Dimensions seldom should be out of scale; but if they are, through error or necessary change, a carefully worded note should be added.

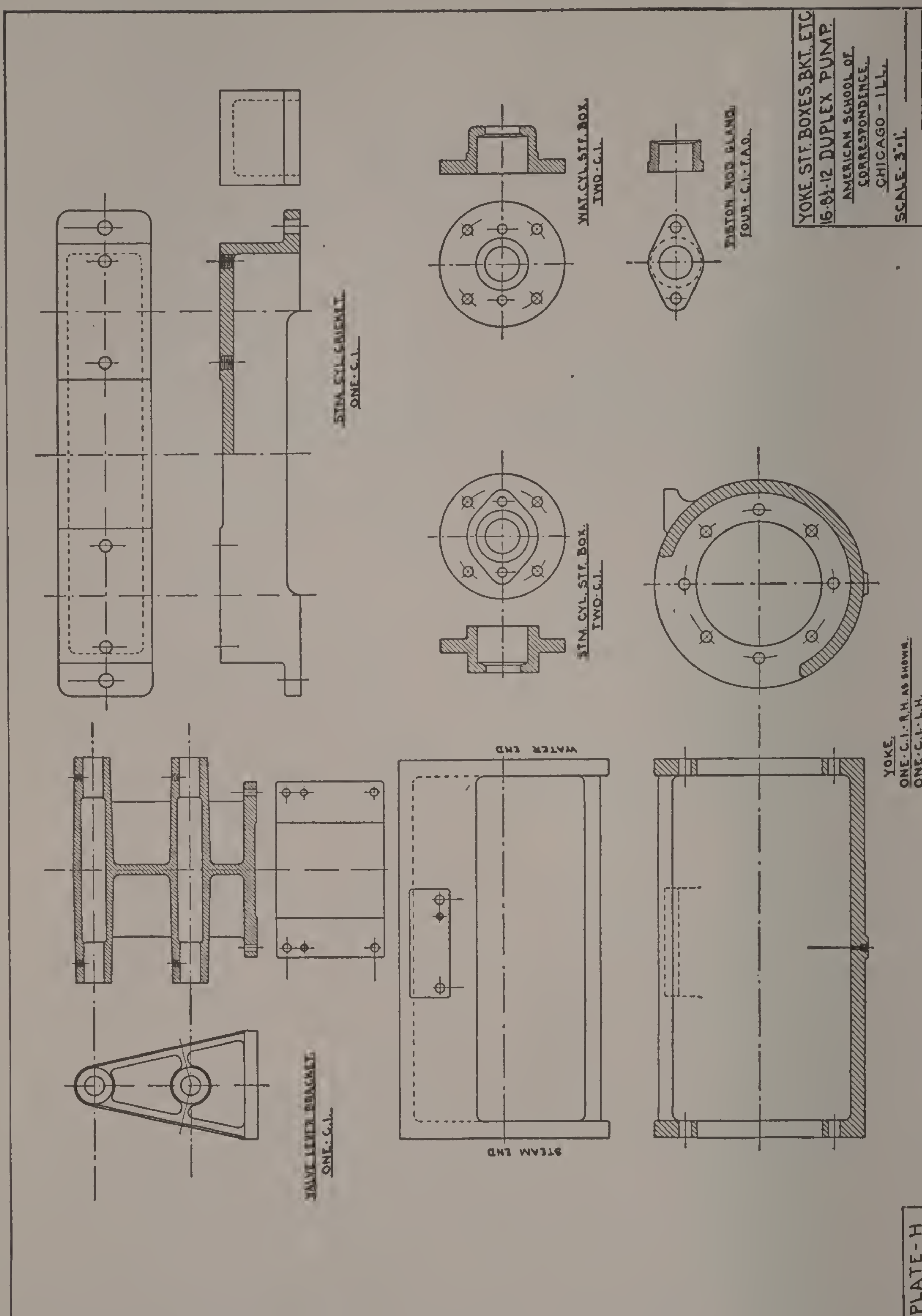
Molding and Machining. No special features of molding or machining are noteworthy on Plate G.

PLATE H. YOKE, STUFFING BOXES, BRACKET, ETC.

Having worked up the layouts of Plates E and F, the student has enough information to proceed with Plate H. This, like Plate B, is without dimensions, the student's work being to make the drawing and fill in the necessary shop data.

Specifications. The valve-lever bracket is bolted down to its lug on the yoke through holes larger than the bolt, thus permitting slight adjustment. When the proper location is determined, the bracket is positively fixed in position by two dowels, $\frac{1}{2}$ inch in diameter. The holes in both bracket and yoke are drilled through both pieces at the same operation. This very common method of fixing bolted parts of machinery in absolute position not only assures firmness, but also in case of removal, permits the part to be readily and positively replaced in its exact original position.

If possible, the steam cylinder cricket should be of such height that the stone or brick work upon which it rests shall be at the


YOKE, STF. BOXES, BKT. ETC
16-8½-12 DUPLEX PUMP
AMERICAN SCHOOL OF CORRESPONDENCE
CHICAGO - ILL.
SCALE - 3"=1'
STM. CYL. BRACKET.
ONE-C.I.
WAT. CYL. STF. BOX.
TWO-C.I.
PISTON ROD GLAND.
FOUR-C.I.-F.A.O.
STM. CYL. STF. BOX.
TWO-C.I.
YOKE.
ONE-C.I.-R.H. AS SHOWN.
ONE-C.I.-L.H.
WATER END
STEAM END
VALVE LEVER BRACKET.
ONE-C.I.
PLATE-H

same level as that beneath the water cylinder. The tapped holes in the top surface receive bolts from the cylinder foot. These bolts are often used only for shipping purposes, the cylinder foot when the pump is set up being allowed to slide freely on the cricket, thus permitting free expansion and contraction. In such cases the water end is rigidly fastened to the foundation by holding down bolts.

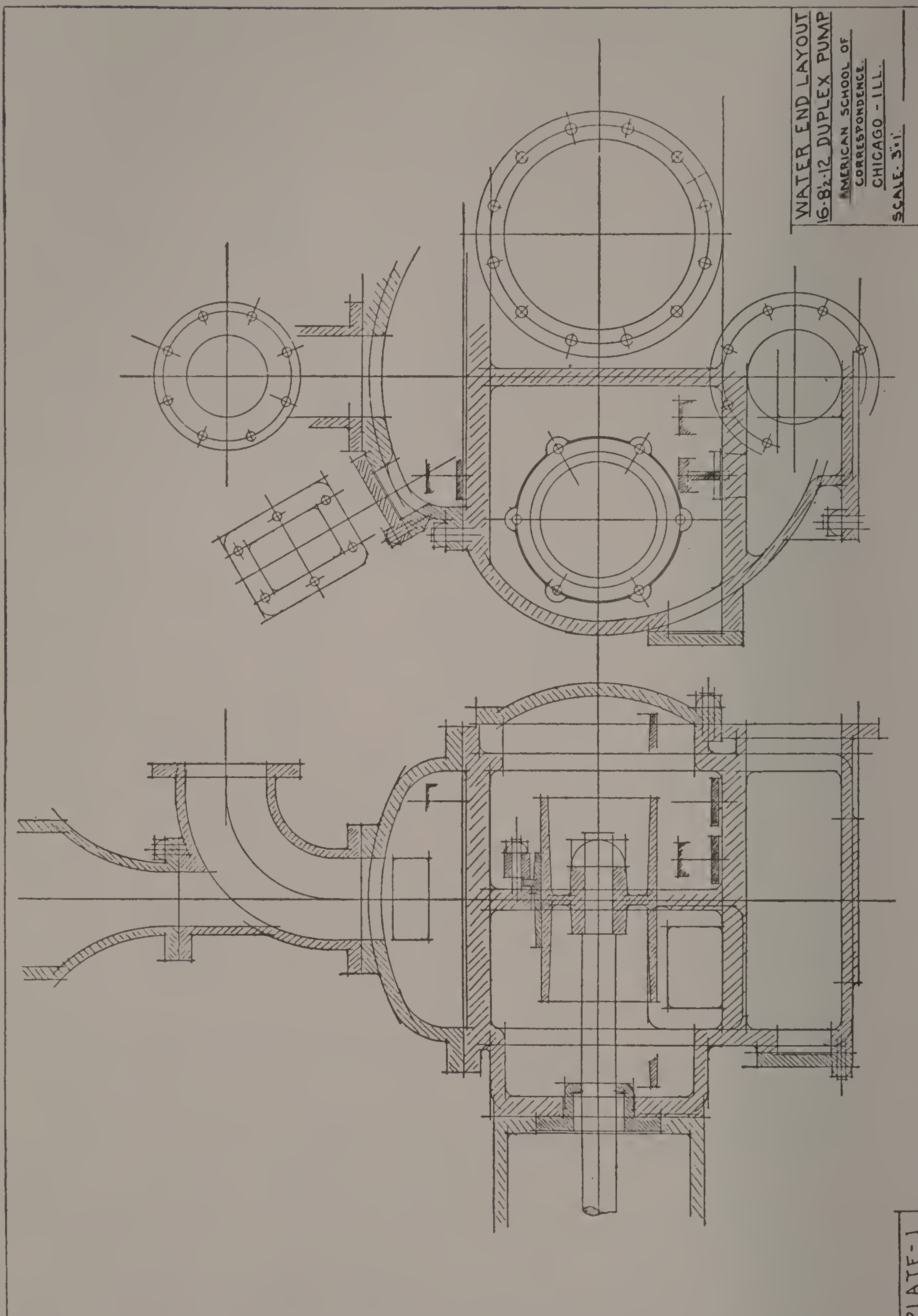
Molding and Machining. The valve lever-bracket would most naturally be molded with the axes of the shafts vertical, the parting line of the mold being the center line of the middle web. This makes quite a long "draw" for the shaft bosses, but the ample taper on the outside overcomes this difficulty. The space between the side webs leaves its own core. The shaft cores stand on end in the mold, which is the best position for strength and stability.

Another method is to have the parting line of the mold on the vertical center line of the bracket, as shown in the end view. In this case the bracket would be cast on its side, and cores must be set for each side of the middle web. The shaft cores are set as easily as before, but in this case lie flat. As with the steam chest, each method has its advantages, which depend largely upon existing conditions. As cored work is generally avoided whenever possible, the first method would probably be chosen.

The shaft bosses are "chamber-cored," to save labor in boring, the bearing surface for the shaft being only a short distance at the ends. The chamber-core diameter should be enough larger than the shaft so that by no possibility can the cutter run into the rough scale, even if the hole be bored slightly out of line. If it should do this, the labor of caring for the cutters more than offsets the attempted saving of labor.

The yoke is simply a barrel open at each end, and with a piece cut out of its side. The inside evidently must be cored out, and the core is satisfactorily supported at the ends on its horizontal axis. The parting line of the mold may be either the vertical or horizontal axis of the end view, the only difference being that in one case the ledge for the valve bracket will "draw," and in the other case it must be loose on the pattern and "pulled in" after the main pattern is drawn.

The cricket and stuffing boxes present no difficulties. The bore of the stuffing boxes and glands should be from $\frac{1}{32}$ inch to $\frac{1}{16}$ inch


WATER END LAYOUT
16-8½-12 DUPLEX PUMP
AMERICAN SCHOOL OF
CORRESPONDENCE.
CHICAGO - ILL.
SCALE - 3" = 1'.
PLATE - 1

larger than the rod, to allow the fit to be entirely between the rod and the packing.

The horizontal boring machine with a double facing head is adapted to boring and facing the yoke flanges. The drilling is accomplished as before by templet or jig.

Attention is called to the tapped holes for oil or grease cups on the valve-lever bracket. The holes on the lower boss cannot be drilled strictly as shown, because the drill shank will not clear the upper boss. They should be swung around the boss at such an angle as will allow the drill to clear. This is a good instance of the common error of drawing details which cannot be made, and constant watch must be kept to avoid such mistakes.

PLATE I. WATER END LAYOUT

Specifications. In the preceding work, the completed plates were used to assist the student in developing the layout drawings for other parts of the pump. In this Section, Plates K and L,, being given in full detail, offer a good start for the development of the water cylinder, which is the purpose of Plate I. As before, work should begin at the inside and progress outwards. Thus the piston rod with its nut should be drawn first, the hub of the plunger built around it, then the plunger barrel, the bushing, and ring to clamp the bushing. The limits of the plunger travel should be sketched in, and the valve outline shown, in order to determine clearances. The progress of Plate I is on exactly the same basis as that stated in detail for the steam cylinder layout; hence it need not be repeated.

Plunger and Bushing. The points controlling the design of the water end must, however, be studied to enable the student to work intelligently. The fit of the rod into the plunger hub is loose, $\frac{1}{16}$-inch play being allowed, in order to permit the plunger to be guided solely by its bushing, and thus be independent of any change of alignment of the piston rod.

The relative length of plunger and bushing should allow the end of the plunger to overrun the edge of the bushing at the termination of the stroke, to prevent the formation of a shoulder. The bushing is made of brass because of the better bearing of the two dissimilar metals, brass, and iron. Of course there is no lubrication except the water, and the dissimilar metals tend to "cut"

less than if both were alike. The brass bushing also prevents the plunger from "rusting in" in case of long periods of disuse. The bushing being of expensive material is made as light as possible, hence it has no stiffness of its own. Therefore, it is reinforced by a deep cast-iron ring, which also takes the bolts and clamps the bushing tightly to its ground seat. These stud bolts are usually made of "tobin bronze," a rust-proof material, possessing strength almost as great as that of steel. This arrangement permits ready removal of the bushing when necessary.

Hand Holes. As the parts of the common pump valve illustrated in detail on Plate L must be often replaced during service of the pump, provision must be made for unscrewing the stem and substituting a new one. This must be done through the hand holes provided on the cylinder. The lower valve deck must be located so that the inner valves when unscrewed will not strike the clamp ring. As shown in Plate I, the clearance is pretty small, almost too small, but as it affects only two valves, it will probably cause no inconvenience. No hand holes are necessary for the end chambers, as access to the valves is had by removing the outer heads.

Deck Details. The upper deck may be placed at a height giving sufficient clearance to allow the upper nuts of the clamp ring to be unscrewed with a socket wrench from the end of the pump. These decks are subjected to a severe pounding from the pulsations of the pump, and should be amply strong; $1\frac{3}{4}$ inches is deemed thick enough for this case.

The middle transverse wall may be $1\frac{1}{2}$ inches thick and the middle longitudinal wall a little thinner, about $1\frac{1}{4}$ inches. With high pressures these walls, being flat surfaces and the valve decks likewise, are likely to fracture under the heavy pounding. To avoid making them excessively heavy they are often strongly ribbed, either on the inside or outside, usually the former.

The curving side walls are of better form to withstand pressure, and need not be as thick, 1 inch being sufficient. This can be decreased to $\frac{3}{4}$ inch in the suction passage below the deck, where little pressure exists.

Outer Head. The outer head is also considered strong enough at 1 inch thickness, on account of its curved shape. It requires $\frac{7}{8}$-inch studs. Studs are preferred to tap bolts in this case, as in all

other similar cases, on account of the frequent unscrewing of the nuts for purpose of removal. One or two unscrewings of a tap bolt in cast iron will destroy the tightness of the thread, while the stud, being steel, stands the wear better.

Valve Seats. The valve seats are taper screwed into the deck; they are sometimes forced in on a plain taper fit. They are located as closely as strength of the deck between the holes will permit. It is not well to place the edge of the valve closer than $\frac{1}{2}$ inch from the cylinder walls. The valve holes in the lower deck should be in line, or nearly so, with the holes in the upper deck, in order to allow the shank of the mill to pass through when milling the lower holes.

Miscellaneous Details. The suction opening is 7 inches in diameter, $12\frac{1}{2}$-inch flange, $10\frac{1}{2}$-inch bolt circle, $\frac{3}{4}$-inch tapped holes.

By means of the hand hole at the end of the suction passage, any dirt which may have been brought in through the suction pipe may be removed.

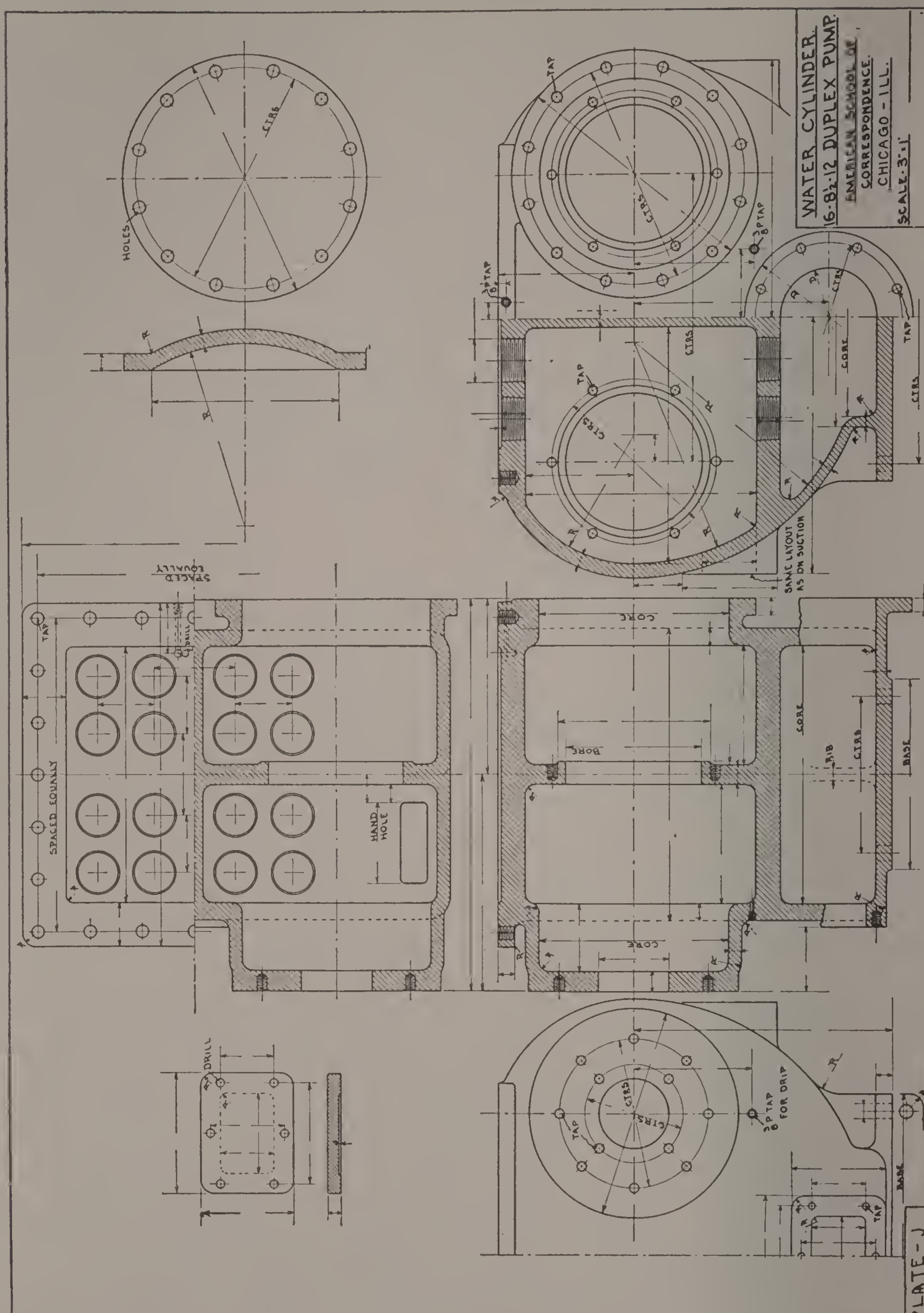
The water cylinder cap, discharge ell and air chamber may be laid out from the detail Plate K, and the student must do this to see that the parts actually go together properly.

With the foregoing discussion the student should be able to produce Plate I, which is the preliminary step to the detail drawing of the water cylinder as shown on Plate J.

PLATE J. WATER CYLINDER

Complications in Design. The water cylinder is, perhaps, the most complicated detail that the student will meet in this set of plates. Fundamentally, it is simply a box with curved sides, divided by the several walls into five compartments, each of which communicates with the outside by a round nozzle or flange. If this basic idea be kept constantly in mind, the student will have no trouble in building up the detailed design.

This fundamental conception of a complicated piece is a very important idea, and should be developed carefully by the student. It is one of the great secrets of good design, both from an artistic and a commercial standpoint. We often see a machine which seems to begin anywhere and end nowhere; it appears to be a miscellaneous collection of bosses, lugs, ribs, and flanges. There is no general


WATER CYLINDER.
16·8½·12 DUPLEX PUMP.
AMERICAN SCHOOL OF CORRESPONDENCE.
CHICAGO - ILL.
SCALE 3"=1'
PLATE - J
SPACED EQUALLY
HAND HOLE
SAME LAYOUT AS ON SUCTION
CORE
BORE
CTRS
RIB
BASE
TAP
DRILL
HOLES
FOR DRIP

prevailing shape to the structure, no harmony of the lines. This is because the designer, if he may be so called, did not have the fundamental notion of shape, to which all minor details should have been subordinated. He simply grouped parts together, without considering the fundamental structure.

In this water cylinder the box is the basic part of the structure, and its lines must be first developed; they should be designed to convey a smooth, regular, and consistent surface to the eye. Then the nozzles and flanges may be added as subordinate parts; they will merely interrupt, but not destroy, the prevailing outline of the box. The dotted lines in the cross-section views of Plate J show the general shape behind and beneath the nozzles.

The hand holes are the same as on Plate K, and the detail of the cover should specify the number required for both places.

Provision for draining the four chambers of the water cylinder is made by the $\frac{3}{8}$-inch pipe tap holes at the lower deck, and the cap, likewise, by the single hole at the upper deck. Drip cocks are screwed into these holes.

The holding-down bolts should not be less than 1 inch diameter; $1\frac{1}{4}$ inch would perhaps be better; and the holes in the foot should be drilled at least $\frac{1}{8}$ inch large.

Dimensions. It will be noticed that this plate has dimension lines, but no figures. This is because the cylinder is rather difficult to figure, and it is desired to guide the student in arrangement of the figures without lessening the benefit of his study of them. Special attention should be paid to this feature of the plate. Notice that although space for dimensions is restricted, a clear opening is always found for the figures; and when one view seems to offer no space for a figure, another view gives the desired opportunity.

No finish marks or titles are shown on this plate, these being left entirely to the student for insertion.

Molding. The centers of the curves for the sides being on the main horizontal axis of the nozzles, the cylinder, if molded to be cast vertically as shown, will draw readily both ways from this line. The exceptions to this easy draw are the foot, suction nozzle and flange, and hand-hole boss. On account of the inside of the cylinder being cored, these pieces if made loose on the pattern have ample space to be "pulled in" after the main pattern is withdrawn.

The suction passage below the deck communicates with the main core through the valve holes, hence it may be supported from the main core. This involves some difficulty, however. If a three-part flask be used, and another parting established at the center of the suction flange, in addition to the previous one, the problem becomes much simplified.

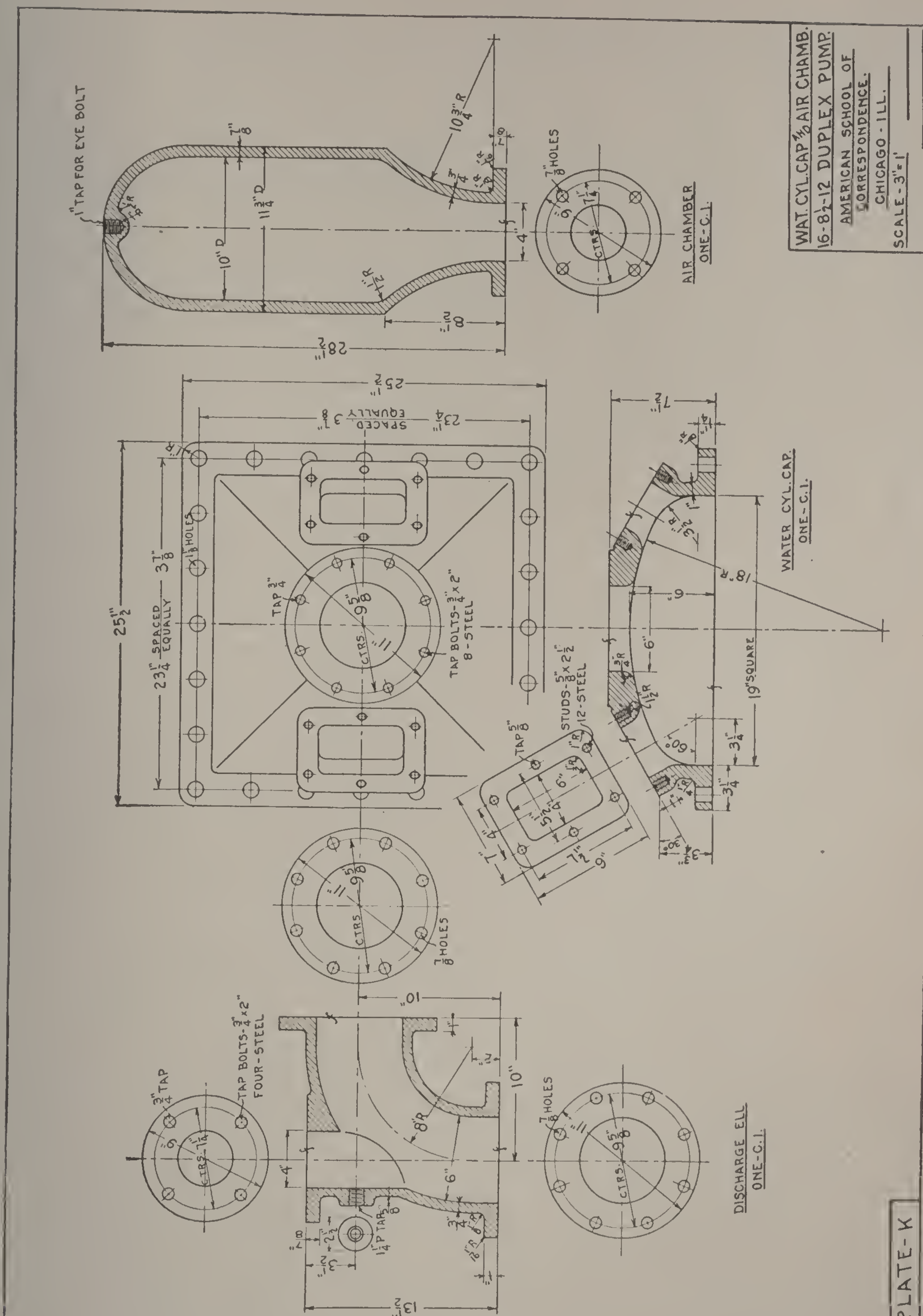
It is desirable to make the four chambers of the cylinder alike in general proportions. It is then possible to make a single core-box, and by the use of loose pieces change the length of the nozzle cores and transpose from right to left, thus saving labor on the pattern. This, however, multiplies the loose pieces on the pattern. The many pieces are likely to become lost and make frequent repair necessary. Hence it is not always wise to use a single core box too much, and good judgment is required to fix the limit.

Machining. Special double horizontal boring machines are now in common use for such cases as this water cylinder. The centers are made adjustable, so that within limits any distance between piston-rod centers can be met. The advantages of double boring are, of course, most obvious for a considerable number of duplicate cylinders.

It will be noticed that the face of the suction flange is carried out flush with the cylinder head face. This affords opportunity for finishing all the end surfaces at a single setting of the tool, whether the work be done on the rotary or reciprocating planer. This same point might have been observed on the small hand-hole boss at the other end of the cylinder, but the advantage gained did not seem to warrant extending the "reach" through the hand hole.

PLATE K. WATER CYLINDER CAP AND AIR CHAMBER

Specifications. For a water cylinder cap of this size, the most difficult problem is to find room for the hand-hole bosses. A hand hole 4 inches × 6 inches is about as small as can be used, and this calls for a flange at least 7 inches × 9 inches. These are the proportions shown on the plate, and since the boss overhangs the bolts in the main-cap flange, it must be cut away underneath to clear the nuts. If three stud bolts are used on each side, this overhang also requires that the nut be "fed on"; that is, screwed on little by little


WAT. CYL. CAP & AIR CHAMB.
16-8½-12 DUPLEX PUMP.
AMERICAN SCHOOL OF
CORRESPONDENCE.
CHICAGO - ILL.
SCALE - 3" = 1'
AIR CHAMBER
ONE - C.I.
WATER CYL. CAP.
ONE - C.I.
DISCHARGE ELL
ONE - C.I.
1" TAP FOR EYE BOLT
TAP BOLTS - ¾" x 2"
8 - STEEL
STUDS - ⅝" x 2½"
12 - STEEL
TAP BOLTS - ¾" x 2"
FOUR - STEEL
19" SQUARE
PLATE - K

as the end of the stud protrudes above the flange when the cap is being lowered into place. This is an awkward process, but it is sometimes necessary.

The discharge ell should have an easy bend; usually the radius is somewhat more than the outside diameter of the pipe. It is customary on this piece to provide an opening for the attachment of a relief valve as shown, $1\frac{1}{4}$-inch pipe tap. This valve can be set to open at a desired pressure, so that the water end may be relieved in case of accidental excessive pressure.

The air chamber provides an air cushion for the water to make the delivery more constant, and take the shock which would otherwise come with hammer-like force and full intensity upon the cylinder. Being placed at the highest point of the water end, air will naturally tend to collect in the air chamber and keep it charged. In some cases, however, a special charging device is necessary.

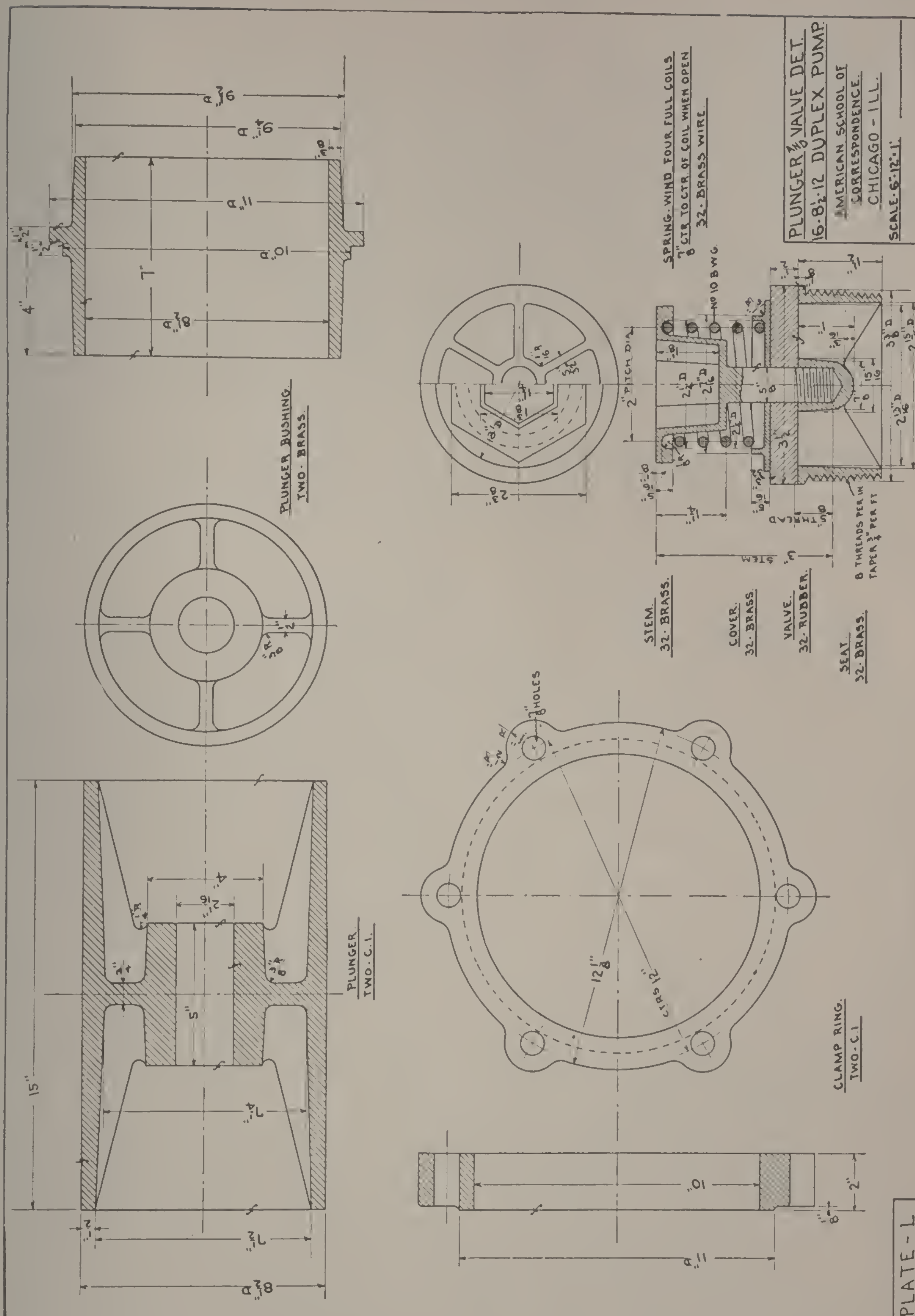
Molding and Machining. The hand holes being at an angle will not "draw". Hence cores must be set for these openings at least, and it may be desirable to core out the whole inside of the cap for the sake of keeping the pattern in good shape by making it solid. Otherwise it is easy to let it leave its own core.

The overhang of the hand-hole bosses requires loose pieces for the overhanging part. They are "pulled" in after the pattern is drawn.

The molding and machining which are further required on details of Plate K are simple, and require no special discussion.

PLATE L. PLUNGER AND VALVE DETAILS

Specifications. Plate L is noticeable for illustrating a method of drawing details not used elsewhere in this set of plates. On the other plates each piece is separately detailed. On Plate L the details of the valve, cover, seat, stem, and spring are shown assembled, and dimensioned without separation. This is an allowable method when clearness is not sacrificed, but it is usually found desirable only with simple construction. It concentrates parts on the drawing, and probably saves some time, besides showing the workman just how the parts go together. The only test which the student need to apply in this, as in any method of detailing, is the test for absolute clearness.


PLUNGER & VALVE DET.
16·8½·12 DUPLEX PUMP
AMERICAN SCHOOL OF
CORRESPONDENCE.
CHICAGO - ILL.
PLUNGER BUSHING
TWO · BRASS.
PLUNGER
TWO · C.I.
CLAMP RING.
TWO · C.I.
STEM.
32 · BRASS.
COVER.
32 · BRASS
VALVE.
32 · RUBBER.
SEAT.
32 · BRASS.
SPRING - WIND FOUR FULL COILS
32 · BRASS WIRE.
PLATE - L

It is believed in the case of the valve as shown that the details are completely illustrated without sacrificing clearness. Special care in putting in dimensions is of necessity required.

The valve stem can be unscrewed either with a socket wrench on the inside or an ordinary fork wrench on the outside.

The seat, after being screwed to position in the deck, is often faced off, to true up any distortion caused by screwing in.

The valve itself, of rubber, can be bought of any desired grade of hardness. The specification for any given set of valves depends upon the quality of the water, the pressure, and the general service of the pump.

Molding and Machining. By reason of the simple nature of the parts on this plate, the molding and machining is left entirely to the original consideration of the student.

PLATE M. FOUNDATION

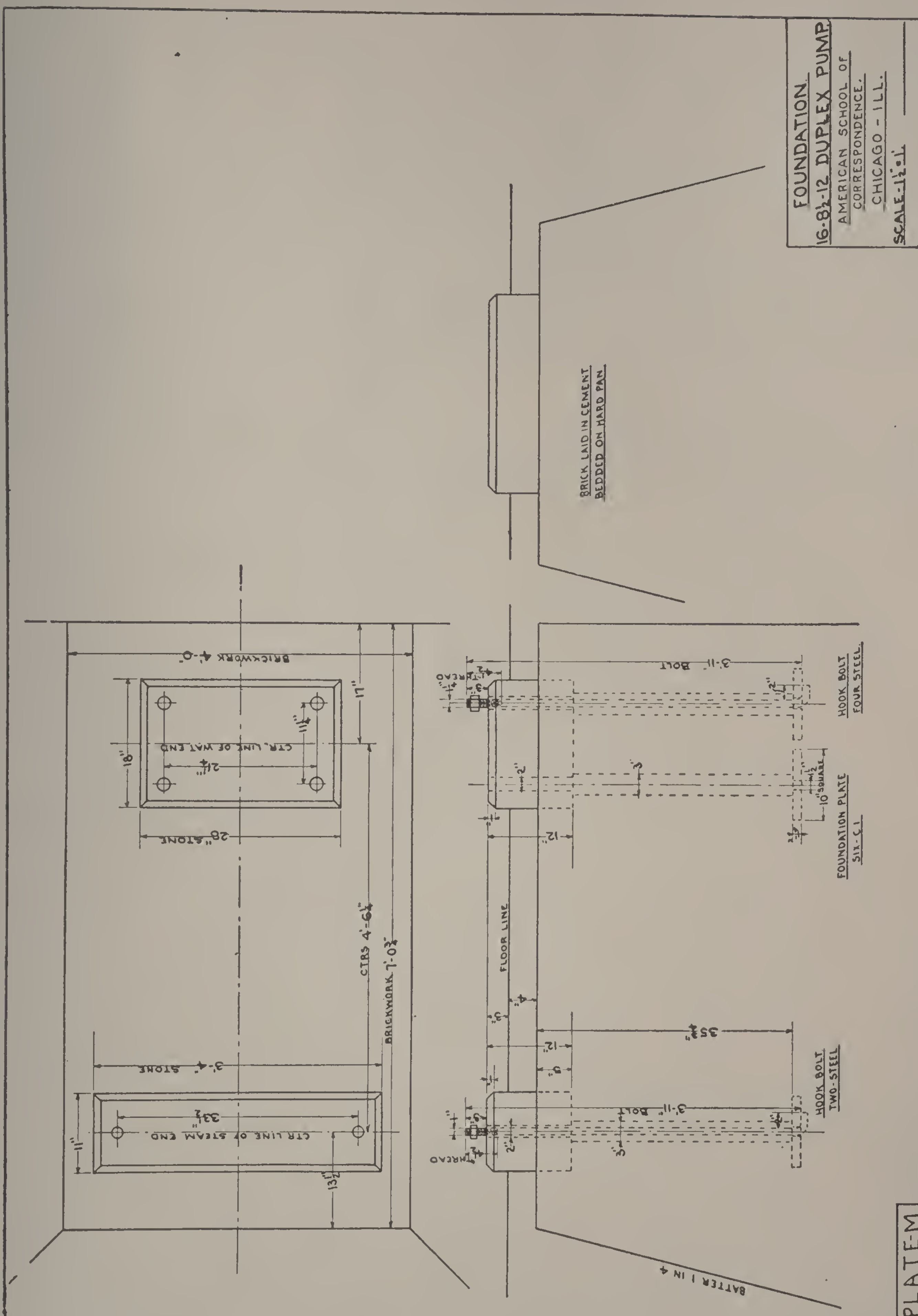
Specifications. Pumps are often set directly upon a foundation of brick, but it makes a better job to bed stones, with surfaces dressed plane and true, into the main foundation, and rest the pump feet upon these stones. The simplest form of holding down bolts is shown on Plate M, a plain hook at the lower end, pulling up against a flat cast-iron plate, to distribute the pressure into the brickwork. These plates are of course bedded, and the bolts set as the foundation is built up. As the subsequent courses are laid some little space is left around the bolts, which may be afterwards filled with cement, thus making the bolts rigid with the foundation.

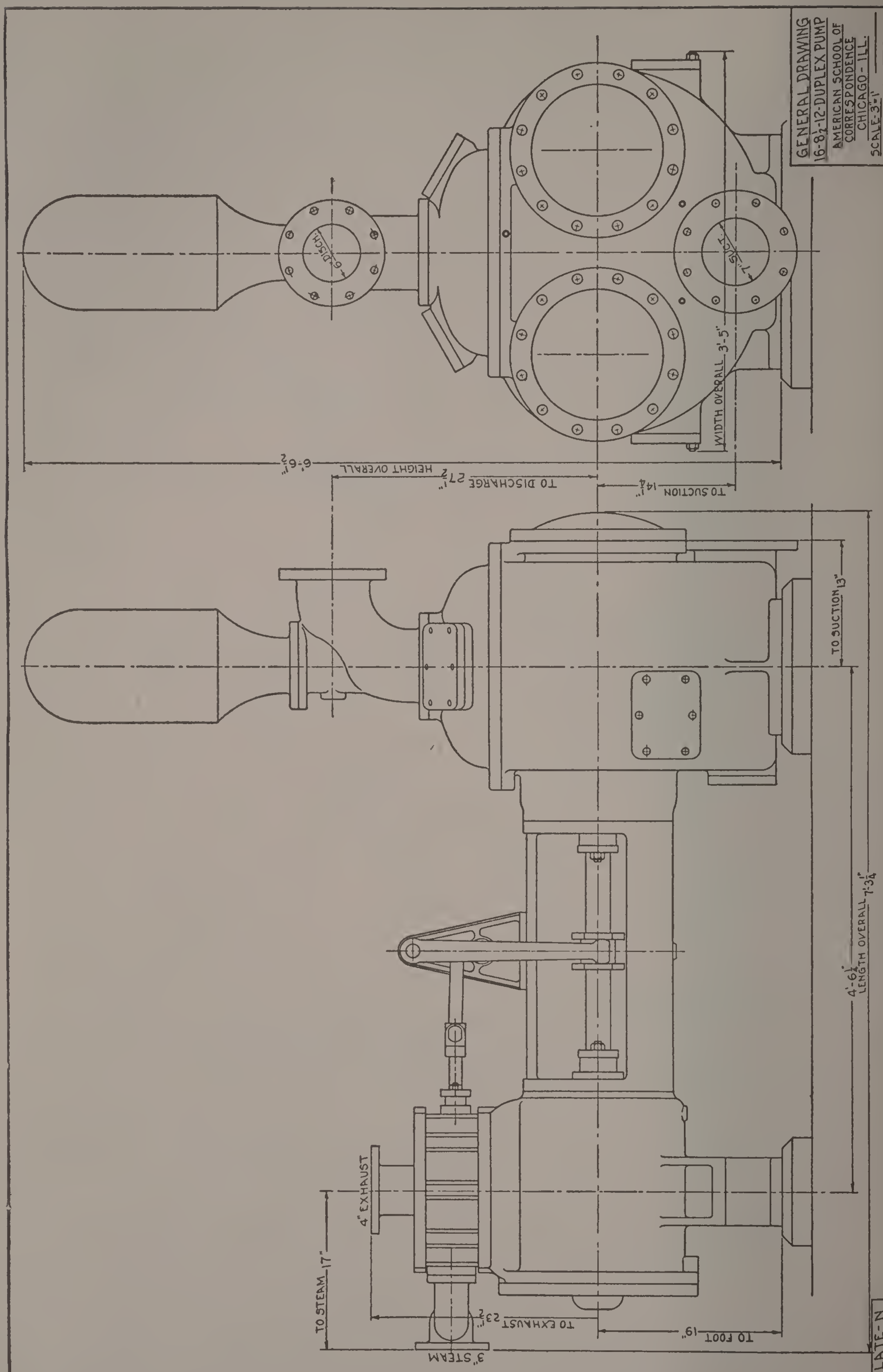
The water end of the foundation has no batter, because the suction pipe often drops vertically down from the end of the pump, and clearness is therefore necessary.

The floor line is placed 4 inches above the brickwork, to allow for the usual 1-inch top floor and 2-inch plank beneath, and still have a space left for shims to level the floor.

PLATE N. GENERAL DRAWING

Assembled Parts. Plate N is an example of a plain, everyday shop drawing, to show the relation of parts and the extreme space occupied by the pump. A great deal of time can be needlessly wasted in producing a drawing of this character, by trying to make too faithful a picture. For example: If all the bolt heads were


FOUNDATION.
16-8½-12 DUPLEX PUMP.
AMERICAN SCHOOL OF CORRESPONDENCE.
CHICAGO - ILL.
SCALE-1½"=1'
BRICK LAID IN CEMENT BEDDED ON HARD PAN
HOOK BOLT FOUR STEEL.
FOUNDATION PLATE SIX-C.I.
HOOK BOLT TWO-STEEL
FLOOR LINE
BATTER 1 IN 4
BRICKWORK 4'-0"
CTR. LINE OF WAT. END
28" STONE
CTRS 4'-6¼"
BRICKWORK 7'-0¾"
3'-4" STONE
CTR LINE OF STEAM END
PLATE-M


GENERAL DRAWING
16-8½-12-DUPLEX PUMP
AMERICAN SCHOOL OF CORRESPONDENCE
CHICAGO - ILL.
SCALE-3"=1'
PLATE-N
WIDTH OVERALL 3'-5"
TO SUCTION 14¼"
TO DISCHARGE 27½"
HEIGHT OVERALL
6'-6½"
6" DISCH.
7" SUCT.
TO SUCTION 13"
LENGTH OVERALL 7'-3¾"
4'-6¼"
4" EXHAUST
TO STEAM 17"
TO EXHAUST 23½"
TO FOOT 19"
3" STEAM

put in, it is safe to say that several hours' extra time would be required for this one item alone. But the drawing would be no better for shop use. Hence all bolt heads and nuts have been left out, except when necessary to show clearance.

An assembly or general drawing of this character should be laid out strictly from the dimensions shown by the details. It thus serves a valuable purpose in checking up figures, and showing whether or not the parts will go together. The method or character of the work in no respect differs from that suggested for the detail drawings.

If a scale of 3 inches = 1 foot be used, the size of sheet must be 24 inches × 36 inches. The student, however, will perhaps find it easier to use a scale of $1\frac{1}{2}$ inches = 1 foot, in which case the ordinary size, 18 inches × 24 inches, will suffice. For such a small scale it will be found undesirable to attempt to put in any very small fillets and corners, although those that can be readily handled by the ordinary bow pen ought not to be omitted. As a matter of fact, the expert draftsman either leaves the corners sharp, as suggested, or puts in the smallest curves freehand.

Order Sheets. Any set of drawings is incomplete unless in connection with it a statement is made in tabular form of the complete make-up of the machine. An infinite variety of ways exists for making the specifications. Sometimes the tabulated data are placed on the general drawing. Most often, however, printed blanks are provided, usually of bond paper, arranged with special reference to the individual shop system and methods of handling work; these blanks are filled in by the draftsman, indexed, and filed as a part of the set of drawings. They can be blue-printed for use in the shops the same as a drawing. From these sheets stock is ordered, checked off, and watched in its process of manufacture.

Order sheets are indispensable in any well-ordered shop. Hence they are illustrated in the pages following the text matter as the final step in the set of pump drawings. They are made as simple as possible, and are not intended to fit any special shop system. As previously stated, the exact form and method of classification can be determined only when the shop conditions are known.

The student, having carefully followed through the preceding pages, must not think that he is master of pump construction, for

even the type illustrated has been but touched upon. The object of the detailed discussion is to get the student in close touch with the spirit of construction, to make his drawings real, serious work. It is hoped that the student will work just as though a machine were to be built from his drawings, and built to sell at a profit. Only in this way can advanced work in mechanical drawing be of benefit to him, for after becoming expert in the use of the instruments, no other advance is possible except advance in *thought.*

DATE. OCT. 10, 1913.

AMERICAN SCHOOL OF CORRESPONDENCE

CHICAGO, ILL.

TYPE. INSIDE PLUNGER.

LIST OF CASTINGS

FOR

16—8½—12 DUPLEX PUMP.

No. Wanted.	Name.	Drawing No.	Patt. or Piece No.	Material.	Remarks.
2	Steam Cylinder	B		C. I.	R. & L.
2	Steam Cylinder Head	B		C. I.	
2	Steam Chest	D		C. I.	
2	Steam-Chest Cover	D		C. I.	
2	Slide Valve	D		C. I.	
1	Steam Pipe	D		C. I.	
1	Exhaust Tee	D		C. I.	
2	Valve Stem Gland	D		C. I.	
2	Piston	C		C. I.	
8	Piston Pipe Plug, $1\frac{1}{2}''$	C		C. I.	
4	Piston Packing Ring	C		C. I.	
2	Spool	C		C. I.	
1	Steam Cylinder Cricket	H		C. I.	
2	Steam Cylinder Stuffing Box	H		C. I.	
2	Water Cylinder Stuffing Box	H		C. I.	
4	Piston-Rod Gland	H		C. I.	
1	Valve-Lever Bracket	H		C. I.	
2	Yoke	H		C. I.	R.& L.
1	Short Rocker Arm	G		C. I.	
1	Long Rocker Arm	G		C. I.	
2	Valve Stem Link	G		C. I.	
1	Water Cylinder	J		C. I.	
2	Water Cylinder Head	J		C. I.	
3	Hand Hole Cover	J		C. I.	
1	Water Cylinder Cap	K		C. I.	
1	Air Chamber	K		C. I.	
1	Discharge Ell	K		C. I.	
2	Plunger	L		C. I.	
2	Plunger Bushing	L		Brass	
2	Clamp Ring	L		C. I.	
32	Valve Stem	L		Brass	
32	Valve Cover	L		Brass	
32	Valve Seat	L		Brass	
6	Foundation Plate	M		C. I.	

DATE. OCT. 10, 1913.

AMERICAN SCHOOL OF CORRESPONDENCE

TYPE. INSIDE PLUNGER.

CHICAGO, ILL.

LIST OF STEEL AND MISCELLANEOUS PARTS

FOR

16—8½—12 DUPLEX PUMP.

No. Wanted.	Name.	Drawing No.	Patt. or Piece No.	Material.	Remarks
2	Valve Steam Head	C		St.	Drop Forging.
2	Piston Rod	C		C. R. S.	
2	Valve Stem	C		St.	
1	Long P. R. Lever	G		St.	Forging
1	Short P. R. Lever	G		St.	Forging
1	Upper Rocker Shaft	G		St.	
1	Lower Rocker Shaft	G		St.	
2	Rocker Arm Pin	G		St.	
2	Link Pin	G		St.	
1	Long P. R. Lever Key	G		St.	Drop Forging
1	Short P. R. Lever Key	G		St.	Drop Forging
2	Rocker Arm Key	G		St.	Drop Forging
32	Valve Spring	L		Bs. wire	Spring Temper
32	Valve	L		Rubber	Medium

DATE. OCT. 10, 1913

AMERICAN SCHOOL OF CORRESPONDENCE

TYPE. INSIDE PLUNGER.

CHICAGO, ILL.

LIST OF BOLTS, NUTS, AND PINS.

FOR

16—8½—12 DUPLEX PUMP.

No. Wanted.	Name.		Drawing No.	Patt. or Piece No.	Material.	Remarks.
24	Cylinder Head	Stud $\frac{7}{8}$ x $3\frac{1}{4}$	B		St.	
20	Steam Chest	Stud $\frac{3}{4}$ x $8\frac{3}{4}$	B		St.	
4	Valve Stem Gland	Stud $\frac{5}{8}$ x $4\frac{3}{4}$	D		St.	
8	Piston-Rod Gland	Stud $\frac{3}{4}$ x 4	H		St.	
24	Water Cylinder Head	Stud $\frac{7}{8}$ x $3\frac{1}{4}$	J		St.	
12	Clamp Ring	Stud $\frac{3}{4}$ x $4\frac{1}{2}$	J		Tobin bz	
24	Water Cylinder Cap	Stud 1 x $3\frac{1}{2}$	J		St.	
18	Hand Hole Cover	Stud $\frac{5}{8}$ x $2\frac{1}{2}$	J		St.	
12	Hand Hole Cover	Stud $\frac{5}{8}$ x $2\frac{1}{2}$	K		St.	
8	Exhaust Tee	Tap Bolt $\frac{5}{8}$ x $1\frac{3}{4}$	B		St.	
16	Yoke	Tap Bolt $\frac{3}{4}$ x 2	B		St.	
8	Steam Cyl. Stf. Box	Tap Bolt $\frac{3}{4}$ x $1\frac{3}{4}$	B		St.	
8	Steam Pipe	Tap Bolt $\frac{5}{8}$ x $1\frac{1}{2}$	D		St.	
4	Valve-Lever Bracket	Tap Bolt $\frac{5}{8}$ x $1\frac{3}{4}$	D		St.	
4	Steam Cyl. Cricket	Tap Bolt 1 x $2\frac{1}{4}$	D		St.	
16	Yoke	Tap Bolt $\frac{3}{4}$ x 2	J		St.	
8	Water Cyl. Stf. Box	Tap Bolt $\frac{3}{4}$ x $1\frac{3}{4}$	J		St.	
8	Discharge Ell	Tap Bolt $\frac{3}{4}$ x 2	K		St.	
4	Air Chamber	Tap Bolt $\frac{3}{4}$ x 2	K		St.	
2	Hook Bolt (special)	1 x 3′—11″	M		St.	
4	Hook Bolt (special)	$1\frac{1}{4}$ x 3′—11″	M		St.	
1	Eye Bolt	Standard 1″	K		St.	
34	Standard Nut	$\frac{5}{8}$			St.	
44	Standard Nut	$\frac{3}{4}$			St.	
36	Standard Nut	$\frac{7}{8}$			St.	
26	Standard Nut	1			St.	
4	Standard Nut	$1\frac{1}{4}$			St.	
4	Standard Nut	2			St.	
8	Special Valve Stem Nut	1			St.	$\frac{3}{4}$ Thick
4	Piston-Rod Split Pin	$\frac{1}{4}$ x 2	C		St.	
2	Spool Taper Pin No. 10 Morse Taper		C		St.	4″ long
4	Valve Bracket Dowel Pin	$\frac{1}{2}$ x 2	H		St.	

DATE.
OCT. 10, 1913.

AMERICAN SCHOOL OF CORRESPONDENCE

TYPE.
INSIDE PLUNGER.

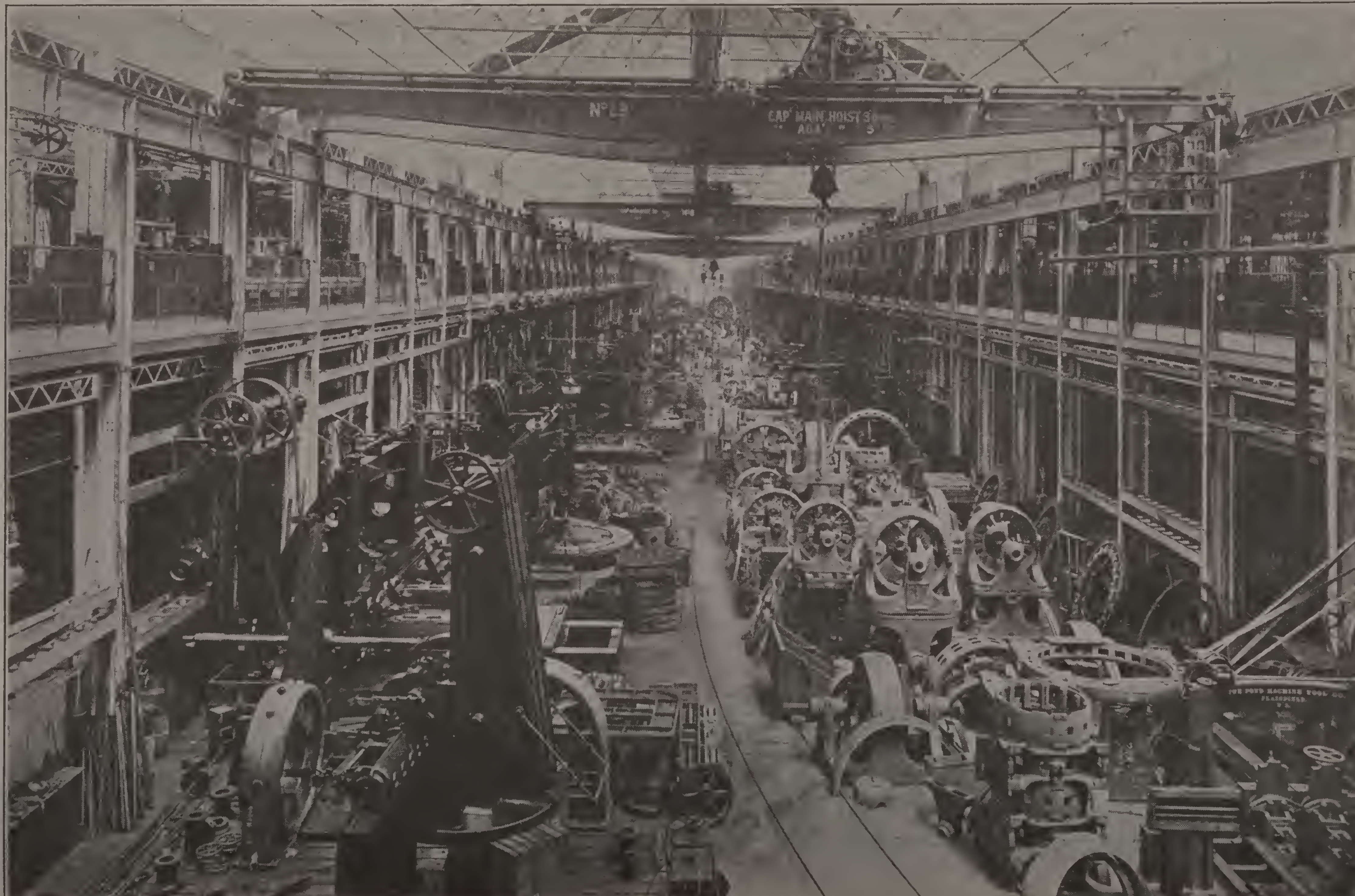
CHICAGO, ILL.

LIST OF SPECIAL FITTINGS, WRENCHES, ETC.

FOR

16—8½—11 DUPLEX PUMP.

No. Wanted.	Name.	Drawing No.	Patt. or Piece No.	Material.	Remarks.
4	Drip Cock ½″	B			
1	Drip Cock ¼″	D			
2	Drip Cock ¼″	H			
4	Oil Cup ¼″	H			
5	Drip Cock ⅜″	J			
1	Relief Valve 1¼″	B			175 lbs. pressure
1	Standard Fork Wrench ⅝″				
1	Standard Fork Wrench ¾″				
1	Standard Fork Wrench ⅞″				
1	Standard Fork Wrench 1″				
1	Socket Wrench ¾″				12″ handle
1	Valve Stem Fork Wrench				
1	Valve Stem Socket Wrench				



SCENE IN ONE OF THE MACHINE SHOPS OF THE WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY

MACHINE DRAWING

PART III B—ELECTRICAL

INTRODUCTION

Requirements. Having learned the general principles involved in making a correct mechanical drawing of any part of a machine, or the machine as a whole, it might be assumed that the student was in a position to work up complete shop drawings of any piece of apparatus when given the necessary data. However, this is hardly the case. The previous work took up the subject from the standpoint of proper portrayal, the proper way to represent a given object in the form of a drawing, without emphasizing the use to which it is to be put.

While it is absolutely necessary that the draftsman have a thorough knowledge of the theory and practice of line drawings, it is also essential that he go farther and attain as well a complete understanding of the uses to which the drawings are to be put. He must look at the whole drawing or set of drawings as a means to an end, the building of the machine or piece of apparatus.

Necessity of Thorough Groundwork. We cannot emphasize too strongly the necessity for a thorough grasp of the work done heretofore. One cannot hope to attain proficiency in machine drawing unless one has previously learned to make line drawings accurately and correctly. It is not a question of having the necessary information available in the form of books or instructions, but of having the information in one's mind, and the ability to produce the drawing at one's finger tips. The principles set forth in the previous works and the elementary training secured in the thorough mastery and study of those principles will alone form the proper foundation for the following work and help to produce an efficient draftsman.

A Drawing Must be a Form of Instruction. The making of drawings will now be taken up from the standpoint of their practical

use in the shop for the production of a complete machine. We must look at the drawing no longer as a "picture" but as a practical form of instruction to the pattern maker, to the foundryman, to the machinist, or to the assembler. Our object is no longer to show the machine or the part, but to give to the shopman such information that he may build the machine.

Variations from the theoretical principles heretofore set forth will be found in plenty, but every variation will have its practical reason. Only a small part of the whole of a piece may be shown, when that small part tells the whole story to the shopman. The proper laws of projection may not be followed or the crosshatching may be omitted entirely from a cross section, but these liberties will be taken by the draftsman only that the drawing may be more clear.

It should not be assumed because of the above statements that a knowledge of the essential principles will not help in the making of practical drawings. The truth is quite the contrary. Unless one knows the principles from the beginning to the end he dare not take liberties for fear these liberties will confuse instead of clarify the work.

Essentials of a Good Drawing. As stated in one of the earlier books on this subject,* the two chief essentials of a shop drawing are:

(1) Absolutely complete and definite instructions from designer to workman.

(2) Least possible cost in dollars and cents of production of the drawing measured by the draftsman's time.

Complete Instructions. Of the above the first is the easier to determine, once the drawing is in the shop and in the hands of the workman. The least question as to form or dimension stamps the drawing as bad and the draftsman as a poor workman. This does not mean that a drawing must be a mass of lines and dimensions nor that everything must be shown on each drawing; in fact, the confusion which would result from such drawings would be as bad as the uncertainty caused by incomplete work. The exact shape and every necessary dimension must be shown, but no unnecessary line must be drawn to hinder and confuse the workman.

*Charles L. Griffin, Machine Drawing, Part III A.

In this connection, it is well to state that many manufacturers prefer that much of the information be given in the form of notes or tables, if it will help to eliminate confusing lines or dimensions on the drawings. Such practices vary widely in different shops, and no definite rules can be laid down.

Cost of Drawings. As to the second point—the cost of the drawing—it is harder to tell when "cheapness" is a real economy. The first point is so firmly fixed as a part of the second that for the cost you must always consider the two together. If a perfect shop drawing can be made cheaply, that is real economy. To make a poor shop drawing cheaply is the greatest extravagance. A draftsman may produce a fairly good shop drawing but may reach this end by unsystematic and haphazard work; the result is high cost of the drawing and at best only fair results. Another draftsman may, although apparently working at a slower rate, reach the same end by careful and systematic work in less time. The drawings of the second man will be cheaper, and the chances are that his care and systematic procedure will in time assure the production of better and better work.

System is essential to cheap drawings. No draftsman can hope to start his work in a careless and haphazard manner and complete it in a reasonable time or even be sure that it is complete when it seems to be. A definite start, a definite system of building up the drawing from that start, and a definite end in view will go far toward teaching the draftsman to produce good drawings at the minimum expense.

With the above points constantly in mind, we can proceed to a demonstration of how a set of shop drawings are produced. In order to get the most good from this demonstration, much of it must be worked out in detail by the student himself. It is to be hoped that this work will go far toward instilling in his mind the principles involved and the necessity for constant thought, close application, and hard work.

The theoretical considerations involved in the design of a direct-current generator are beyond the scope of this work, but the production of shop drawings of such a machine, once the designing engineer has supplied the data, will make an excellent study.

DESIGN OF A DIRECT-CURRENT GENERATOR

General Specifications. The set of plates* which will be used presents complete drawings for a multipole direct-current generator having six main poles and commutating poles, running at a speed of 600 revolutions per minute, and rated 250 volts 300 kilowatts. This rating must be abbreviated on the drawings, the manufacturer having a definite form which is always followed, thus: *M. P. C.* 6-300-600-*L*-250 *V*. *M. P.* means multipolar; *C* means commutating field; *L* means the form; and the figures indicate number of poles, kilowatt output, speed, and voltage, respectively. This tells all that is necessary regarding the rating of the machine. Form letters may sometimes be added to indicate some special features of design, but these are peculiar to the manufacturer.

Material Supplied to Designing Draftsman. In any electric machine, the design must be an intermingling of electrical and mechanical features. The designing engineer usually gives more of the mechanical details than in some other classes of machinery because these details affect the electrical features. Practice varies in every manufacturing plant to some extent in this respect. Thus, in one place the engineer may go so far as to determine the size of the shaft necessary, while in another the calculation of some of the electrical features may be left to the designing draftsman.

In general, the designing draftsman is supplied with complete tables of the electrical features giving all details of the various windings, the length or size of the magnetic circuits, and the material to be used for them, together with any other features of design which must be followed in order to meet the requirements. The electrical features may be given in the form of tables which may give all necessary data as to size and number of conductors in fields and armature, the size and arrangement of slots in the armature laminations, and the kind of insulation and its arrangement. From this data the draftsman must make his drawings complete in every detail, so that the machine can be built in the shops. The information contained in the drawings must be such that every workman, from the pattern maker to the assembler, can do his work without other help.

*Courtesy of the General Electric Company, Schenectady, N. Y.

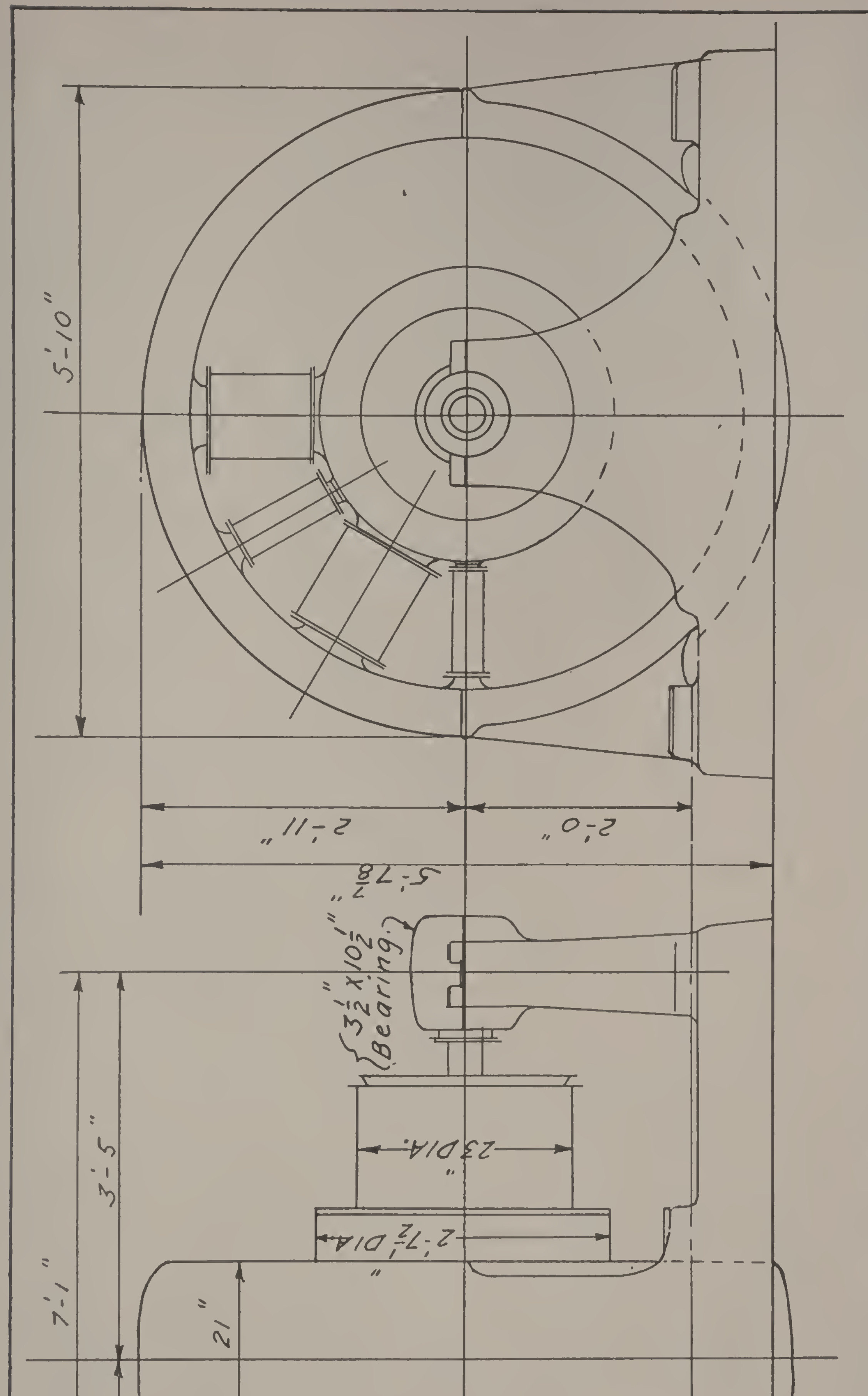

5'-10"
2'-11"
2'-0"
5'-7 1/2"
{3 1/2" x 10 1/2" Bearing.}
23" DIA.
2'-7 1/2" DIA
21"
7'-1"
3'-5"
2'-0"
{4 1/2" x 13 1/2" Bearing}

PLATE A

PRELIMINARY LAYOUT SKETCH

Pencil Sketch. The designing draftsman may make first a sketch or preliminary drawing showing the outline of the machine, with such dimensions as may be determined from the designer's data.

PLATE A. GENERAL OUTLINE DRAWING

Plate A shows such a preliminary outline drawing. It will be seen that this drawing is more or less rough. There is no detail and there are no dimensions except such as are determined by the designer's data and the known requirements as to over-all dimensions, such as length from face of coupling to end of outboard bearing, height from floor to center line of shaft, etc. No pains have been taken to make the drawing of value to the shopman, since it is used only in the drafting room. It gives the detail man a better idea of the whole machine than the data submitted by the designer. While the lines are put in without much regard to detail or accuracy, they convey the proper idea, and time spent in unessentials would be wasted on such a drawing.

Value of Layout Drawing. The draftsman now has, in addition to the designing data, a sketch giving information to the eye as well as to the mind. He sees at once that a start must be made from this and, if he is a good draftsman, he knows that he must as far as possible work out completely each part as it is reached. He should avoid starting any part unless enough is already known to finish that part. This principle cannot always be followed, since some parts are interdependent and must be worked up together before they can be detailed individually.

DETAILS OF ARMATURE AND COMMUTATOR

In the case in hand, it might seem the logical thing to start with the center of the machine—the shaft—and work outward, completing each part as it is reached. However, if we start with the shaft, we soon find that we do not have sufficient data to complete the drawing. While the designer has given some data from which we could start, as for instance the length between bearings and the weight, we must also know the dimensions of the armature and commutator spiders before the shaft drawing can be completed; therefore, we must first work up the armature and commutator.

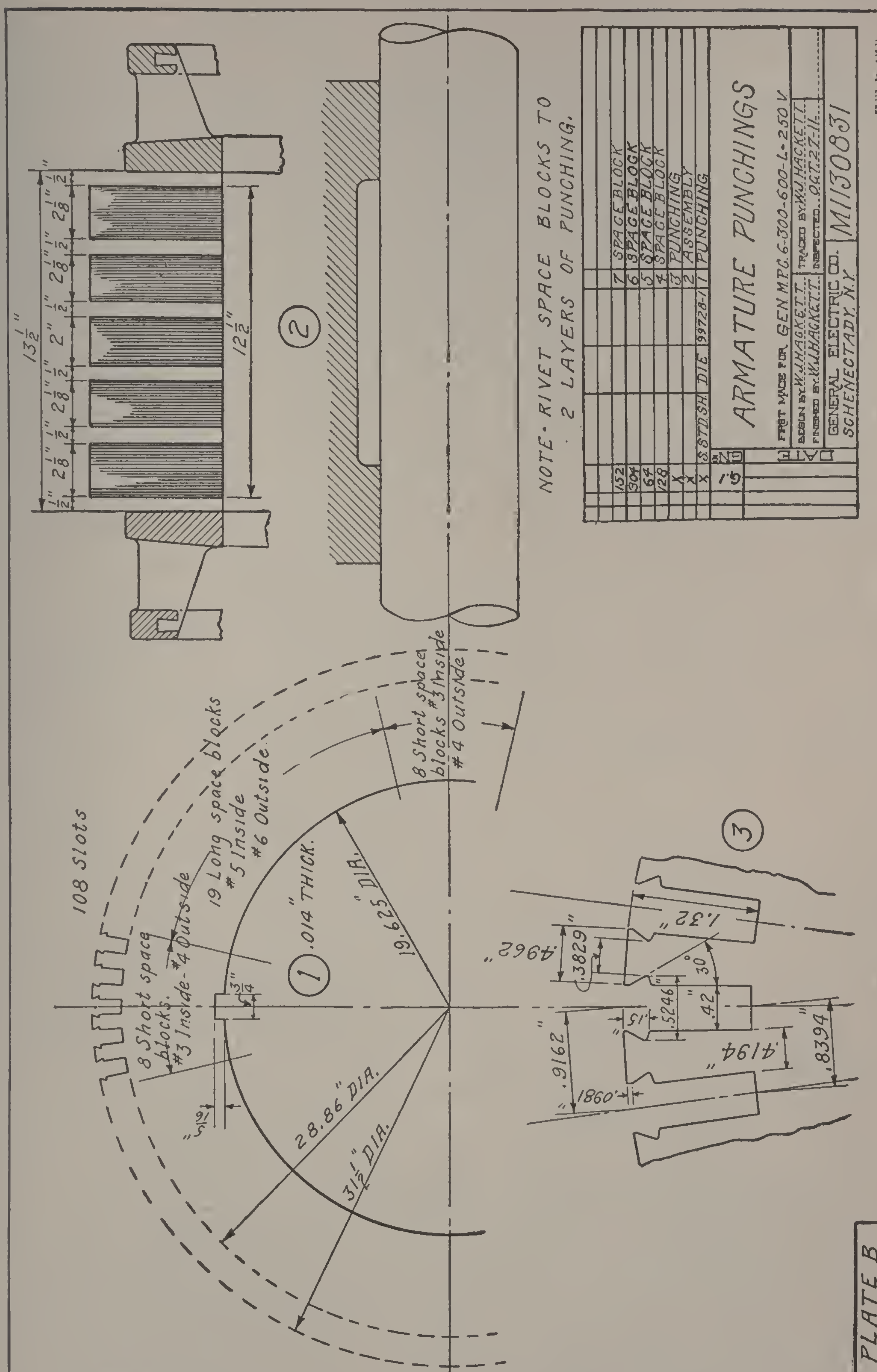

NOTE: RIVET SPACE BLOCKS TO 2 LAYERS OF PUNCHING.
SPACE BLOCK
SPACE BLOCK
SPACE BLOCK
SPACE BLOCK
PUNCHING
ASSEMBLY
PUNCHING
ARMATURE PUNCHINGS
GENERAL ELECTRIC CO.
SCHENECTADY, N.Y.
108 Slots
8 Short space blocks. #3 Inside-#4 Outside
19 Long space blocks #5 Inside #6 Outside
8 Short space blocks #3 Inside #4 Outside
.014" THICK.
19.625" DIA.
28.86" DIA.
$31\frac{1}{2}$" DIA.
PLATE B

PLATE B. ARMATURE PUNCHINGS

The armature laminations, Fig. 1, can very easily be drawn, since the designer has given all the necessary data as to dimensions, and it is only necessary for the draftsman to put this data on a drawing for the use of the shopman.

Details of Slots. It will be noted that the slots are very carefully detailed, Fig. 3, the dimensions in all cases being given in decimals and figured to several decimal places, depending upon the accuracy necessary. The actual dimensions of the piece and the slots are taken from the engineer's design data.

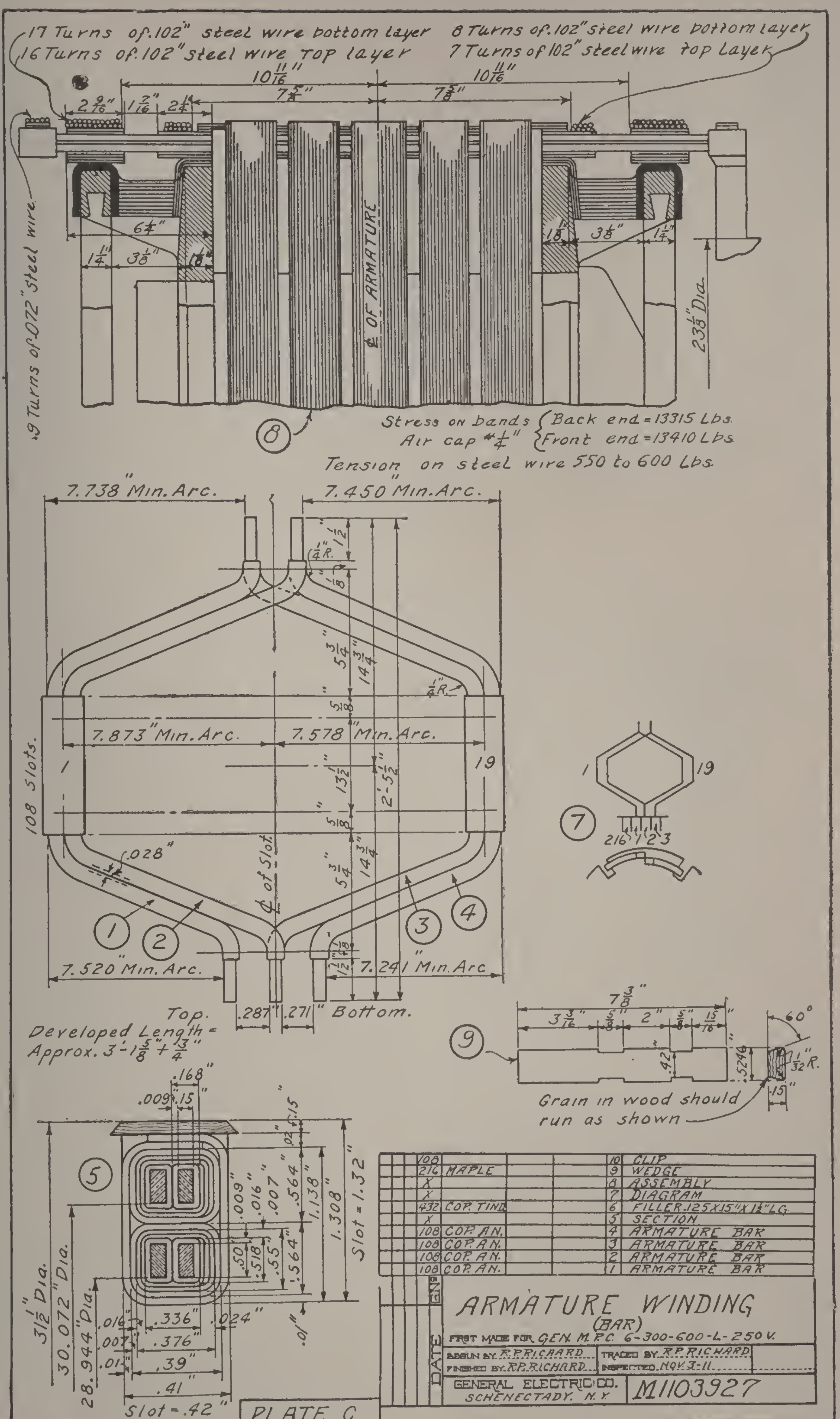
Assembly of Punchings. The punchings are assembled as shown in Fig. 2 of this plate to give over-all dimensions as shown; that is, the number of pieces is determined in assembling only by the total thickness required. A $\frac{3}{4}'' \times \frac{5}{16}''$ keyway is provided, the use of which will be understood when the spider is drawn. The space blocks are inserted at intervals in order that openings may be left through the armature for ventilation. These space blocks are not detailed on this drawing and consist merely of metal pieces which, it will be noted, are riveted to two laminations, so that they are held rigidly in place.

PLATE C. ARMATURE WINDINGS

Layout of Winding. It will next be necessary to lay out the armature windings themselves in order that we may complete the details of the flanges and spider. Note now how the draftsman has made a diagram, Fig. 7, showing with single lines how the conductors are to be arranged. He has taken the first and nineteenth slots, showing the conductors as lines; he has shown the first three and the last commutator bars, to show their relation to the conductors; and finally, he has made an end view, showing the relation of the conductors in the slots.

Detail Drawing of Coils. He next draws the same set of coils to such a scale as will show all necessary detail, Figs. 1, 2, 3, and 4, putting on full and complete dimensions as obtained from the design data and the dimensions of the armature core, and as determined from the coils themselves.

Cross Section of Coil in Slot. A cross section of one set of conductors in one slot is next drawn, Fig. 5. This must necessarily


17 Turns of .102" steel wire bottom layer
16 Turns of .102" steel wire top layer
8 Turns of .102" steel wire bottom layer
7 Turns of .102" steel wire top layer
9 Turns of .072" steel wire
℄ OF ARMATURE
23 5/8" Dia.
Stress on bands { Back end = 13315 Lbs.
Air gap #1/4" { Front end = 13410 Lbs.
Tension on steel wire 550 to 600 Lbs.
7.738" Min. Arc.
7.450" Min. Arc.
7.873" Min. Arc.
7.578" Min. Arc.
108 Slots.
℄ of Slot.
7.520" Min. Arc.
7.241" Min. Arc.
Top.
Bottom.
Developed Length = Approx. 3'-1 5/8" + 3/4"
Grain in wood should run as shown
Slot = 1.32"
Slot = .42"
31 1/2" Dia.
30.072" Dia.
28.944" Dia.
108 | | 10 CLIP
216 MAPLE | | 9 WEDGE
X | | 8 ASSEMBLY
X | | 7 DIAGRAM
432 COP. TIND | | 6 FILLER .125 X 15" X 1 1/2" LG.
X | | 5 SECTION
108 COP. AN. | | 4 ARMATURE BAR
108 COP. AN. | | 3 ARMATURE BAR
108 COP. AN. | | 2 ARMATURE BAR
108 COP. AN. | | 1 ARMATURE BAR
ARMATURE WINDING
(BAR)
FIRST MADE FOR GEN. M.P.C. 6-300-600-L-250 V.
BEGUN BY R.P. RICHARD
TRACED BY R.P. RICHARD
FINISHED BY R.P. RICHARD
INSPECTED NOV. 3-11
GENERAL ELECTRIC CO.
SCHENECTADY, N.Y.
M1103927
PLATE C

be drawn to a very large scale, such as twice the size, in order that all dimensions may be shown without sacrificing clearness. In this section it should be noted that several diametrical dimensions are given and that the dimensions of the slot are shown along with the corresponding dimensions of the coil.

Side View of Assembly in Armature Core. A side view of the coil assembled in the armature core is next shown, Fig. 8. This view shows a number of details which are covered completely with very little labor. For instance, the binding wires are shown and described completely, although nothing more than a section is drawn. This illustrates very well the use of good explanatory notes and their value as labor savers. This view also shows the armature flanges and determines their general dimensions, as related to the coils.

Another point in connection with this drawing which should be given attention is the method of calling for the various parts. It will be noted that a table is included in the lower right hand corner. This table gives on the right the name of each part, with a number which refers to a corresponding number in the body of the drawing. Note that these numbers on the drawing are made large and enclosed in circles, and that arrows are added where necessary to call attention to the proper part. The table contains, still farther to the left, the proper material to be used and the number of parts required. Such tables are used by some drafting rooms and undoubtedly prevent confusion due to placing too much data on the body of the drawing.

Another point should be noted. The drawing is made primarily to show the armature coils, and to do this we have a plan, a side elevation, and a section. The plan and elevation do not bear the relation on the sheet that the laws of projection require, but nothing in clearness is sacrificed, space is saved, and the drawing is really made easier to read.

In addition to showing all necessary details of the coils, sufficient data is given from which to make the next drawing. In other words, we have determined enough of the physical dimensions of the armature flanges to know how they must be built to support properly the ends of the coils, giving necessary clearances for insulation, etc.

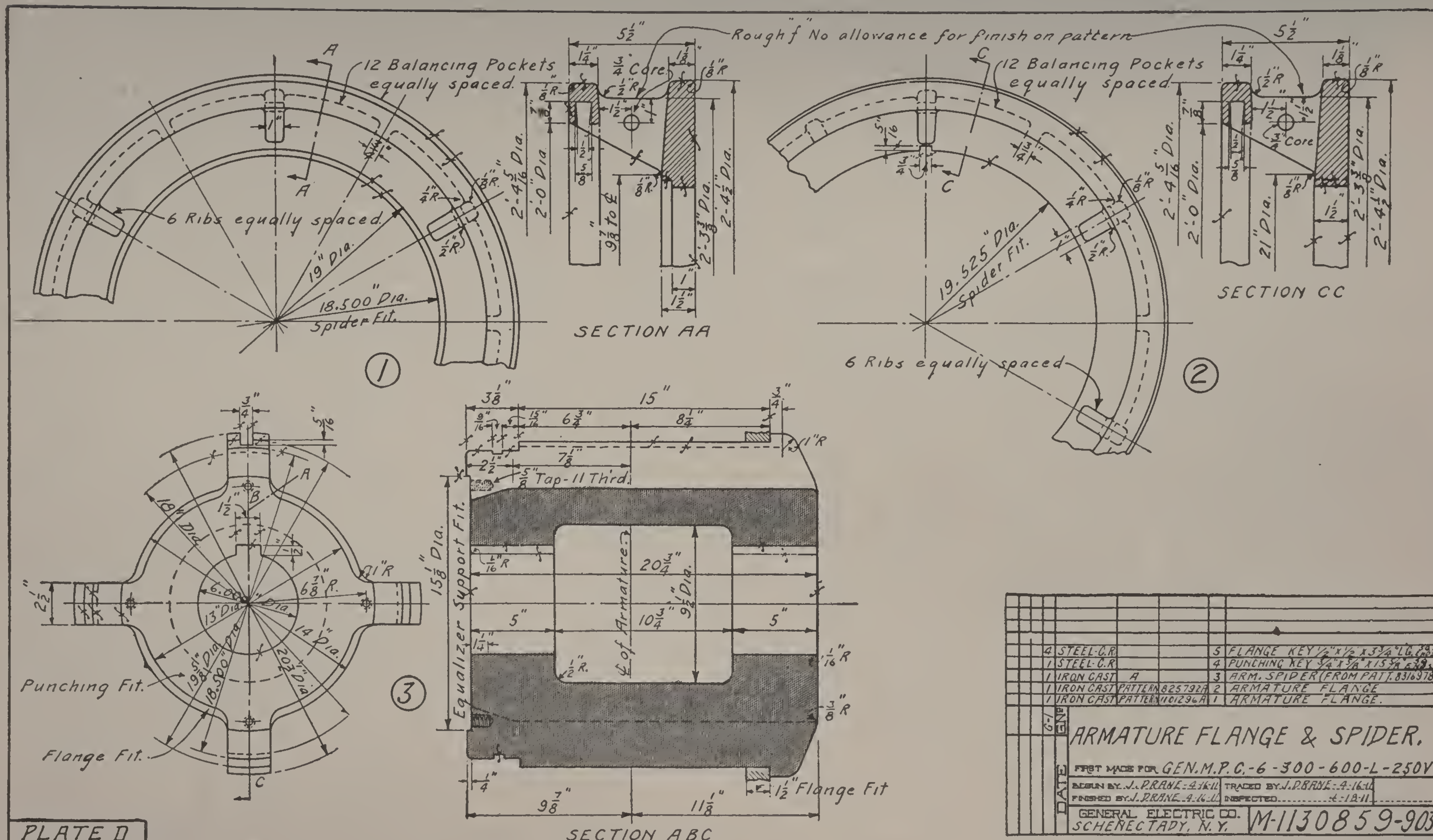

Rough f No allowance for finish on pattern
12 Balancing Pockets equally spaced.
6 Ribs equally spaced.
19" Dia.
18.500" Dia. Spider Fit.
SECTION AA
12 Balancing Pockets equally spaced.
19.525" Dia. Spider Fit.
6 Ribs equally spaced
SECTION CC
5/8" Tap-11 Thrd.
Equalizer Support Fit.
℄ of Armature
1 1/2" Flange Fit
SECTION ABC
Punching Fit.
Flange Fit.
PLATE D
4 STEEL-C.R. 5 FLANGE KEY
1 STEEL-C.R. 4 PUNCHING KEY
1 IRON CAST A 3 ARM. SPIDER
1 IRON CAST PATTERN 825792A 2 ARMATURE FLANGE
1 IRON CAST PATTERN 1101296A 1 ARMATURE FLANGE.
ARMATURE FLANGE & SPIDER.
FIRST MADE FOR GEN.M.P.C.-6-300-600-L-250V
BEGUN BY J. DRANE 4-16-11
FINISHED BY J. DRANE 4-16-11
GENERAL ELECTRIC CO.
SCHENECTADY, N.Y.
M-1130859-903

PLATE D. ARMATURE FLANGES AND SPIDER

We come logically then to the armature flanges and the spider.

Difference Between Front and Back Flanges. The two flanges are quite similar in everything except as regards their mounting on the spider. The one for the back end of the armature, Fig. 2, merely slips back over the arms of the spider against a shoulder. The laminations are placed on the spider, and then the front flange, Fig. 1, must be arranged to press the laminations against the back one, and must be held solidly in place. Note that the inside diameter of the back flange is given in decimals to a thousandth of an inch and marked spider fit. Now note the corresponding dimension on the front flange. While the dimension is an even eighteen and one-half inches it is given to three decimals, indicating that the machining must be done so that the given dimension is within one thousandth of an inch. This shows the workman at once where the fine work is to be done and, compared with other dimensions, shows the relative care which must be taken to make the size as shown.

This drawing also shows, very clearly, how a whole piece may be covered in the drawing by showing only a part. Nothing whatever could be added to the drawing by showing the whole of these two flanges, while more space would be required and more time would be needed to draw it.

It will be noted that the sections are identified on the plans by lines drawn across them at the points where the sections are taken, these lines being lettered, and a note added below the section giving the proper reference.

Finish Notes for Shopman. Another thing should be noted as showing how the draftsman must consider the pattern maker. The pattern maker must make proper allowance for shrinkage and for machining, and wherever a part is marked "finish" by means of the usual *f*, he will add to the dimensions shown in making his pattern. Now note the arms of these flanges, shown in section on Figs. 1 and 2. Instead of putting the *f* across the surface to be finished, a note is given which tells the pattern maker that, while it is to be rough finished, no extra allowance is necessary.

This simply illustrates the original point of the whole matter; the drawings are for the shopman, and every point, no matter how

small, must be covered so that there can be no doubt in his mind as to how to proceed.

Armature Spider Details. Now, taking up the spider, Fig. 3, it will be seen that the outside dimensions are determined by those of the flanges. The shaft diameter must now be calculated, if not given by the designer, and we can proceed to complete this drawing.

Note how the center of the spider is cored out to save metal, how fit dimensions are carefully marked in and given in decimals where close work is desired. Note the keyways for laminations, front flange, and shaft, and note how the keys are called for in the table in the corner.

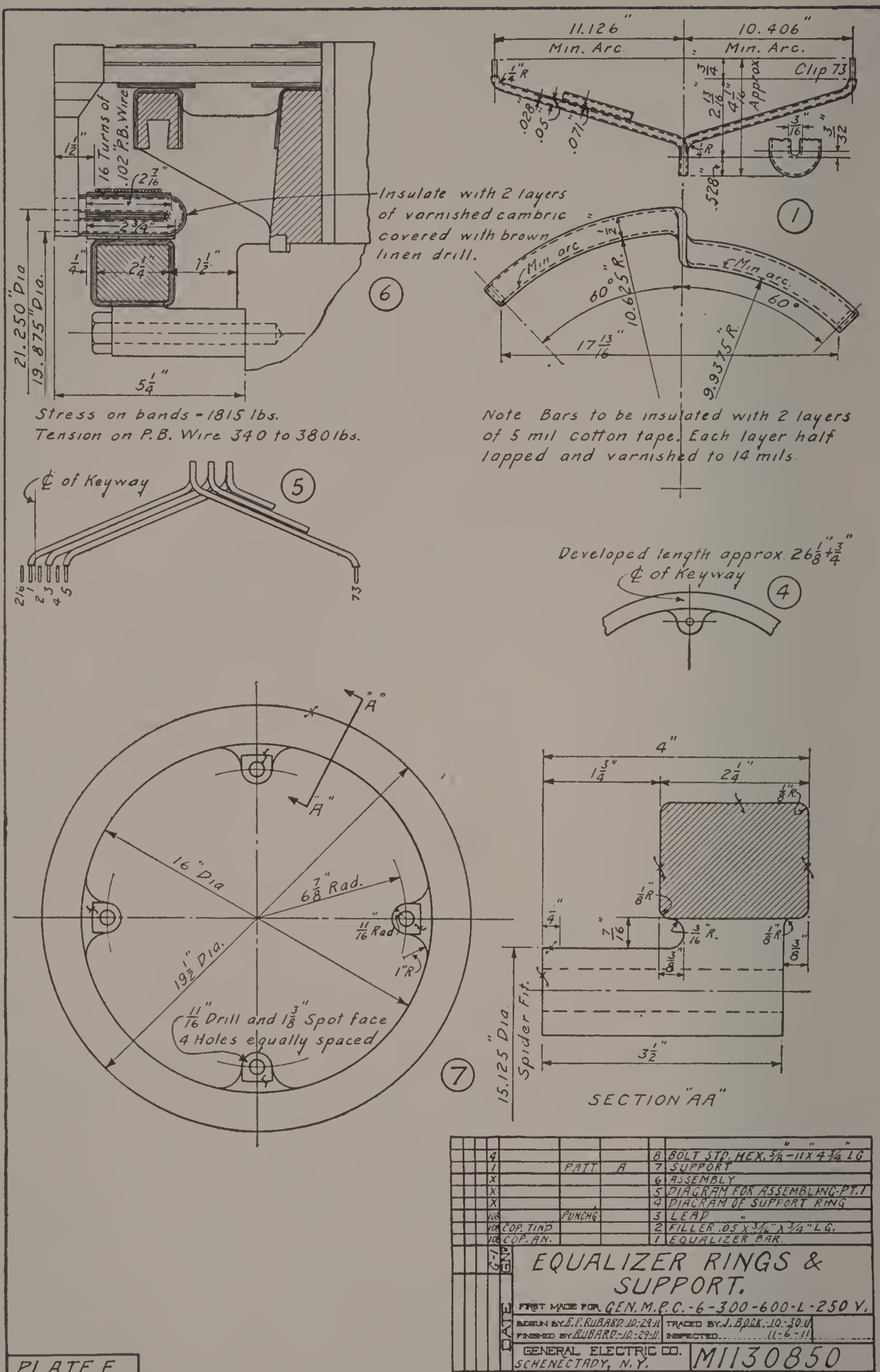
Another point of interest is the way in which the draftsman has shown a section through one arm of the spider but has shown the other one full. By "bending" the section line *A B C* he has added clearness to the drawing and saved crosshatching considerable space. As to this crosshatching, many drawing rooms save time by the method shown here. Instead of making the usual parallel lines, the space is filled in with a pencil, giving a clouded appearance when blue-printed.

On the left end of the spider are shown the shoulder and tapped holes for the equalizer support. The equalizer support cannot be drawn until the equalizer rings have been laid out and the dimensions determined (See Plate E).

PLATE E. EQUALIZER RINGS AND SUPPORT

General Details. The equalizer rings just referred to may now be designed. First a diagram is drawn showing the general shape and the points at which they are connected into the risers, Fig. 5. The details are next worked up, showing the exact form and all dimensions, Fig. 1. A note giving insulation data is added, the thickness being given as usual in mils or thousandths of an inch.

Assembly Drawing. From the above an assembly is developed, Fig. 6, showing the rings in place under the armature coils and supported by a ring attached to the armature spider. As in the case of the armature coils, the binding wires are shown and notes included giving number of turns, size of wire, stress on the bands, and tension on the wires.


Insulate with 2 layers of varnished cambric covered with brown linen drill.
16 Turns of .102" P.B. Wire
21.250" Dia
19.875" Dia.
Stress on bands = 1815 lbs.
Tension on P.B. Wire 340 to 380 lbs.
11.126" Min. Arc.
10.406" Min. Arc.
Clip 73
Approx
9.9375" R.
Note Bars to be insulated with 2 layers of 5 mil cotton tape. Each layer half lopped and varnished to 14 mils.
℄ of Keyway
Developed length approx. 26 1/8" + 3/4"
℄ of Keyway
16" Dia
6 7/8" Rad.
19 1/2" Dia.
11/16" Drill and 1 3/8" Spot face
4 Holes equally spaced
15.125" Dia. Spider Fit.
SECTION "AA"
BOLT STD. HEX. 3/8 - 11 X 4 3/4 LG
SUPPORT
ASSEMBLY
DIAGRAM FOR ASSEMBLING PT. 1
DIAGRAM OF SUPPORT RING
LEAD
FILLER .05 X 3/16" X 3/4" LG.
EQUALIZER BAR.
PATT.
PUNCHG
COP. TIND
COP. AN.
EQUALIZER RINGS & SUPPORT.
FIRST MADE FOR GEN. M.P.C.-6-300-600-L-250 V.
DESIGN BY E.P. RUBARD 10-29-11
FINISHED BY RUBARD 10-29-11
TRACED BY J. BOCK 10-30-11
INSPECTED 11-6-11
GENERAL ELECTRIC CO. SCHENECTADY, N.Y.
M1130850
PLATE E

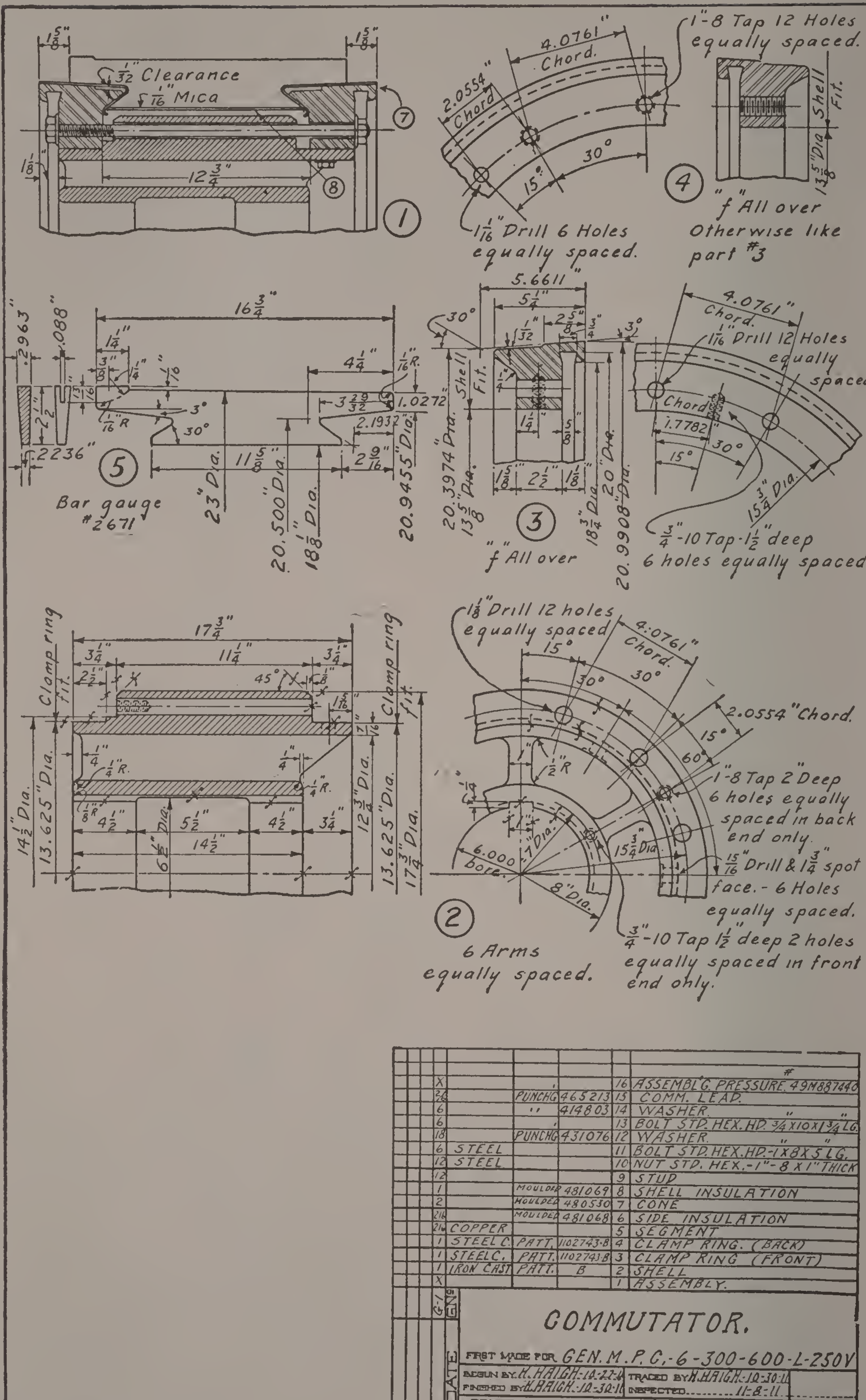
Equalizer Ring Support. From the data already given in Fig. 6 and on Plate D, the support for the equalizer rings may now be drawn, Fig. 7. The principal dimensions are determined from the previous drawings and it only remains to work out the details, which need no explanation.

PLATE F. COMMUTATOR DETAILS

Commutator Drawing Requires Special Care. Now we come to the commutator, clamping rings, and spider or shell. Plate F is a splendid example of detail work where the draftsman must work out dimensions to the finest point, considering only not the foundry man, the machinist, and the assembler, but the ultimate result to be obtained and the use to which this part of the machine is to be put. Here we have a device which must consist of 216 copper bars insulated from each other, from the supporting shell, and from the clamping rings, having a given length and wearing depth and assembled in a cylinder having a diameter of about 23 inches. It is obvious that the only way these bars can be held in place is by clamping rings drawn up against beveled surfaces on the ends of the bars, with proper insulation between the individual bars and between the bars and the rings. Insulation must also be placed between the bars and the shell.

Dimensions of Commutator Sections. It will be seen that the dimensions can only be expressed in decimals, if accurate results are to be obtained. Note now the width of the top of each bar—.2963 inch shown in Fig. 5—and, taking this dimension and the insulation thickness between each bar of .0382 inch, check back and find the circumferential length. Now compare this figure with the circumference of a circle whose diameter is 23 inches. It will be found that the thickness of the bars has been figured so closely that the total error in the length of the circumference will only be a matter of thousandths of an inch in a total length of some six feet. Such work is only possible by means of very fine gages. A reference will be found to a gage number, which means that the tool maker must make a gage accurate within one ten-thousandth of an inch, which will be used by the workman in making these bars.

It should be noted that all dimensions between concentric surfaces are referred to radial or diametrical distances. This



1/32" Clearance
1/16" Mica
1 1/16" Drill 6 Holes equally spaced.
1"-8 Tap 12 Holes equally spaced.
4.0761" Chord.
2.0554" Chord
"f" All over
Otherwise like part #3
Shell Fit.
Bar gauge #2671
1 1/16" Drill 12 Holes equally spaced
3/4"-10 Tap-1 1/2" deep 6 holes equally spaced
1 1/8" Drill 12 holes equally spaced
2.0554" Chord.
1"-8 Tap 2" Deep 6 holes equally spaced in back end only.
15/16" Drill & 1 3/4" spot face.- 6 Holes equally spaced.
3/4"-10 Tap 1 1/2" deep 2 holes equally spaced in front end only.
6.000" bore.
8" Dia.
6 Arms equally spaced.
Clamp ring fit.
X | | | | 16 | ASSEMBL'G. PRESSURE. #49M887446
26 | | PUNCHG | 465213 | 15 | COMM. LEAD.
6 | | " | 414803 | 14 | WASHER.
6 | | | | 13 | BOLT STD. HEX. HD. 3/4" X 10 X 1 3/4" LG.
18 | | PUNCHG | 431076 | 12 | WASHER.
6 | STEEL | | | 11 | BOLT STD. HEX. HD.-1" X 8 X 5" LG.
12 | STEEL | | | 10 | NUT STD. HEX.-1"-8 X 1" THICK
12 | | | | 9 | STUD
1 | | MOULDED | 481069 | 8 | SHELL INSULATION
2 | | MOULDED | 480530 | 7 | CONE
216 | | MOULDED | 481068 | 6 | SIDE INSULATION
216 | COPPER | | | 5 | SEGMENT
1 | STEEL C. | PATT. | 1102743-B | 4 | CLAMP RING. (BACK)
1 | STEEL C. | PATT. | 1102743-B | 3 | CLAMP RING (FRONT)
1 | IRON CAST | PATT. | B | 2 | SHELL
X | | | | 1 | ASSEMBLY.
COMMUTATOR.
FIRST MADE FOR GEN. M. P. C.,-6-300-600-L-250V
BEGUN BY H. HAIGH-10-27-11
FINISHED BY H. HAIGH-10-30-11
TRACED BY H. HAIGH-10-30-11
INSPECTED 11-8-11
GENERAL ELECTRIC CO. SCHENECTADY, N.Y.
M1107403
G-1
DATE

PLATE F

certainly shows that the draftsman understood his business. The whole construction is such that diameters or radii are the fixed dimensions, and any attempt to give these dimensions in any other way would cause the shopman to calculate the diameters with great chance for error.

Complete Information for Shopman. It might be well at this point to emphasize the importance of giving information on the drawing in such a way and in such completeness that the shop man need ask no questions; in fact, modern shop practice requires that the workman work entirely from the drawing and the dimensions given there, and under no circumstances is it permitted the shopman to make any calculations. It should also be remembered that it costs much more to make additions to or changes on a drawing than the same work would have cost, if done when the drawing was made in the first place. And so we see that even so small a thing as one of these commutator bars is given closest attention, and each detail is worked out so that when the whole thing reaches the assembler it will be as easy to put together as if it were two pieces instead of several hundred.

Assembly Drawing. This plate is another good example of how the draftsman may completely describe the whole by showing only a part. The assembled view, Fig. 1, loses nothing by showing a section of less than half the commutator; in fact, to spend time and money showing more would certainly be wasteful. The same may be said of the other parts shown on this plate.

The assembly shown gives the general scheme of placing the parts of the commutator together so as to perform the proper functions. From this, the other details can be developed.

Details of Armature Shell. First we must have a shell for supporting the bars and rings. This can be made in the form of two concentric cylinders with supporting arms between, Fig. 2. The size of the shaft has already been decided upon, so we can start with this dimension. It is not desirable to make this piece fit the shaft throughout its entire length since it would require a difficult job of boring in the shop and would add nothing to the finished piece. The casting is therefore cored out by the foundry man, so that there will be two bearing surfaces each $4\frac{1}{2}$ inches long to be bored, but the central portion of the hub need not be finished.

This saves considerable time in the machine work. The thickness of the hub is only enough for mechanical strength to carry the commutator. The same is true of the arms and outer shell. In other words, as little material is used as possible to give the desired strength, with a proper factor of safety. Thus we have the arms 1 inch thick and, of course, the full length of the shell. The outer shell, having a number of holes through it for the studs for drawing up the rings, must be somewhat thicker than the hub. Also the rings must be considered and these holes spaced so that they will not come too close to the inner edge. The various holes, being rather hard to show clearly, are described in notes at one side of the drawing. These notes give size of hole, threading data when necessary, and any other information as to number, location, or depth that may be required.

It should be noted that those dimensions which must be machined very closely are given, as in other plates, to three and four decimal places. The usual notes and marks as to finish and fits are included.

Clamp Rings. The clamp rings, Figs. 3 and 4, are fairly simple as to form, but accurate and careful work is shown in making the drawings, and the information must be quite as clear and complete as for the more complicated-looking pieces. Note how many dimensions are given and the reasons for them—for instance, the angles of the cone faces which must check with the corresponding angle on the commutator bars, and the radius of the curve between the cone face and the vertical face which must be such as to turn the insulating cone without any tendency to break it. Since these rings are finished all over, a single note to that effect saves the time of putting the usual marks on all finished surfaces.

Surely the shopman will have little trouble in building this commutator from the drawing, with its wealth of detail information. How many dimensions could be omitted and how many lines left out and still be sure of the information being complete? Just enough is shown, just the right number of dimensions are given, to give complete instructions to the shopman at the smallest possible expense. This stands for efficiency in drawing and in building from the drawings.

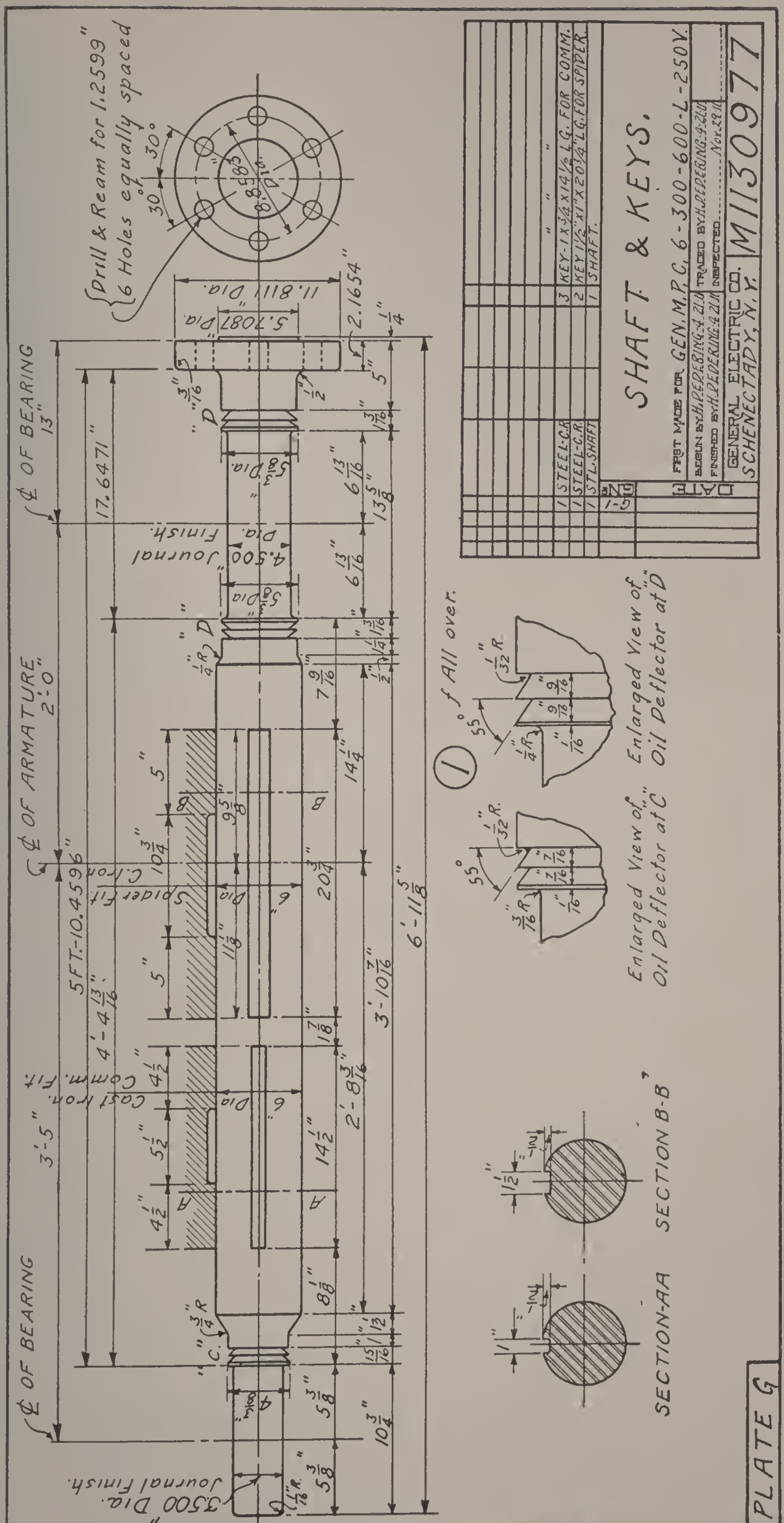

SHAFT & KEYS.
FIRST MADE FOR GEN. M.P.C. 6-300-600-L-250V.
GENERAL ELECTRIC CO.
SCHENECTADY, N.Y.
1 SHAFT.
2 KEY 1½"x1"x20¾" LG. FOR SPIDER.
3 KEY-1x¾x14½ LG. FOR COMM.
STEEL-C.R.
STL-SHAFT.
℄ OF BEARING
℄ OF ARMATURE 2'-0"
℄ OF BEARING 13"
Drill & Ream for 1.2599"
6 Holes equally spaced
11.8111 Dia.
5.7087 Dia.
4.500" Journal Dia. Finish.
3.500" Dia. Journal Finish.
Spider Fit C. Iron
Cast Iron. Comm. Fit.
6'-11⅝"
5FT-10.4596"
17.6471"
SECTION-AA
SECTION B-B
Enlarged View of "C" Oil Deflector at C
Enlarged View of "D" Oil Deflector at D
f All over.
PLATE G

PLATE G. ARMATURE SHAFT

Details and Dimensions. The revolving parts have now been completed with the exception of the shaft. From the previous drawings all data is available for making the shaft drawing as shown in Plate G. The center lines of bearings, the center line of the armature, and the center line of the shaft itself will give the starting points. The size of the main section of the shaft and of the bearings has been determined. Note that the bearing at the coupling end is larger than the other one since the strains there are greater. The total length of bearing between oil deflectors is made slightly greater than the length of bearing to allow for end play of the armature when running.

Oil Rings. If the shaft were extended in smooth lines toward the center, the oil would gradually creep along the shaft until it reached the spider or commutator shell where it would be thrown out into the machine. Rings are therefore formed on the shaft which will throw off the oil inside the bearing housing. These deflectors are shown on a larger scale so that the details can be given more clearly. Sections through the shaft for the purpose of showing the keyways are also given. Note how the finish is given according to whether it is for a fit with some other part or is a polished journal finish.

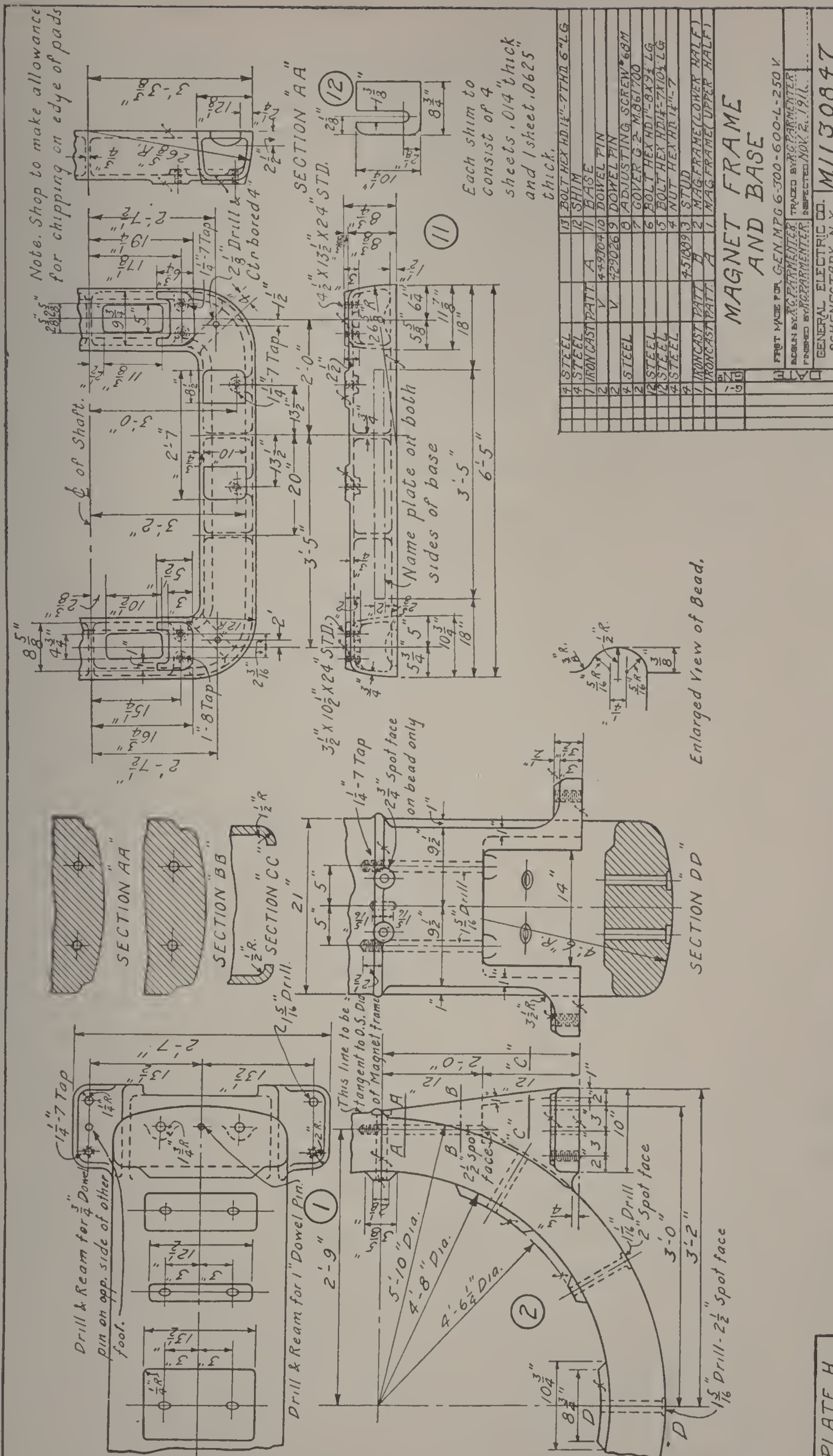
Couplings. The coupling is also shown on this plate, since it forms a part of the shaft. The dimensions are given in decimals where they affect the other half coupling which will be furnished by the manufacturer of the prime mover to which the machine is to be coupled.

The keys are called for in the title table by dimensions, no other information being necessary.

It will be noted that only enough of the sections of armature spider and commutator shell are shown to give their location on the shaft and furnish needed dimensions.

DETAILS OF FIELD FRAME AND COILS

Having completed the revolving member, we now turn our attention to the magnet frame, fields, etc.



MAGNET FRAME AND BASE
GENERAL ELECTRIC CO. SCHENECTADY, N.Y.
M1130847
PLATE H
Note. Shop to make allowance for chipping on edge of pads
SECTION "AA"
SECTION "BB"
SECTION "CC"
SECTION DD
Enlarged View of Bead.
Name plate on both sides of base
Each shim to consist of 4 sheets, .014" thick and 1 sheet, .0625" thick.

PLATE H. MAGNET FRAME AND BASE

General Details. The details of the magnet frame are covered by Plate H. Certain dimensions here are fixed by the electrical design in order to give the proper amount of iron in the frame, the proper size field cores, and proper spacing of fields. The frame is made split horizontally at the center line, and the two parts are symmetrical, except that the lower half must have proper feet at the points where it rests on the base. Only one of the lower quarters, Figs. 1 and 2, is shown in the drawing, since this will give all necessary dimensions and instructions for the entire frame and the lower half is symmetrical about a vertical center line.

Arrangements for Bolting Frame and Pole Pieces. The work on this drawing consists mostly of locating and dimensioning the parts already fixed by the designer and completing the mechanical details. There are some very interesting things to be seen in connection with some of these mechanical details. There is a pole on each side of the machine which must come exactly at the split, Fig. 2. The holes for the bolts which hold these pole pieces must come at a point which will clear the studs holding the two halves of the frame together. Also two of the poles come where the feet are located. It will be seen that the casting is made hollow at this point (see sketch marked *Section "DD"*) and the bolts for these poles are put through from this space. The studs for holding the two halves of the frame together also come down into this space. A steel cover plate is provided so that the rough casting and bolt heads are covered and present a neat appearance. It will be noted that wherever a bolt head comes against the outside of the magnet frame, that place is spot faced, that is, faced off so as to give a flat bearing surface.

Details of Feet. Several sections are shown through the feet so that their form is determined definitely all over. An enlarged view of the bead at the point where the two halves are joined is also shown. These sections and enlarged views help the pattern maker in laying out his pattern drawings, and are an essential part of the drawing.

Details of Base. The base, Fig. 11, is a single iron casting. While this is but a single piece, a great deal of detail is shown in

order that the pattern maker and foundryman will have sufficient information. It will be noted that the casting is hollow, with supporting ribs at intervals to add strength and stiffness, and with bosses on the surface where the magnet frame and pedestals are supported. These latter must, of course, be carefully machined to give the frame and bearing pedestals the proper relative location. This plate also shows the shims, Fig. 12, used for adjusting the height of the magnet frame in order that the armature may be properly centered in the field. These shims are similar in every way to those used for the pole pieces, and serve a similar purpose.

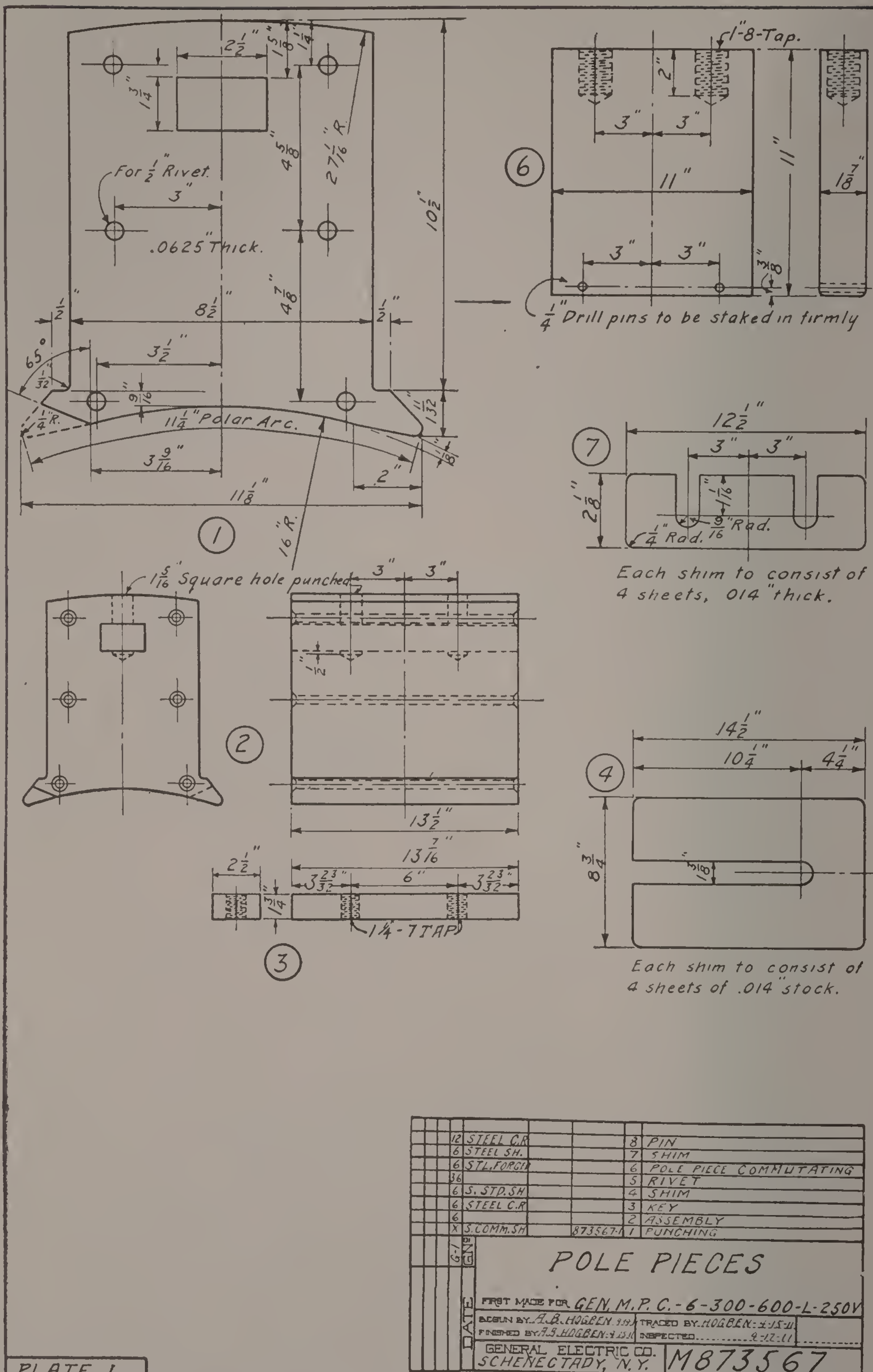
Note in this drawing again, we have an example of the partial picture, the base being symmetrical about the center line of the machine.

PLATE I. POLE PIECES

General Details. The general outlines and dimensions of the pole pieces for the fields are determined by the electrical design, but they must all be covered completely by drawings so that they can be built in the shop. The main fields have laminated pole pieces, that is, the pole piece is made up of thin sheets of steel punched out to definite form, Fig. 1, enough being assembled together to give the required thickness, Fig. 2. The commutating fields, Fig. 6, have solid pole pieces of forged steel. Plate I covers both of these pole pieces.

Field Pole Pieces. The main pole pieces must be riveted together to form a solid piece, and the rivets must be spaced and placed in such a manner as to give the best mechanical construction. The pole tips must be shaded; that is, the amount of iron in the tips must be reduced for electrical reasons. Note how this is accomplished: Each lamination has one tip cut off in a definite manner. The laminations are then assembled with alternate pieces having this cut tip on opposite sides. The actual amount of iron in the tips is then reduced by one-half. The tips are also cut back slightly from a true arc, so that the gap between the pole and the armature is greater at the tip.

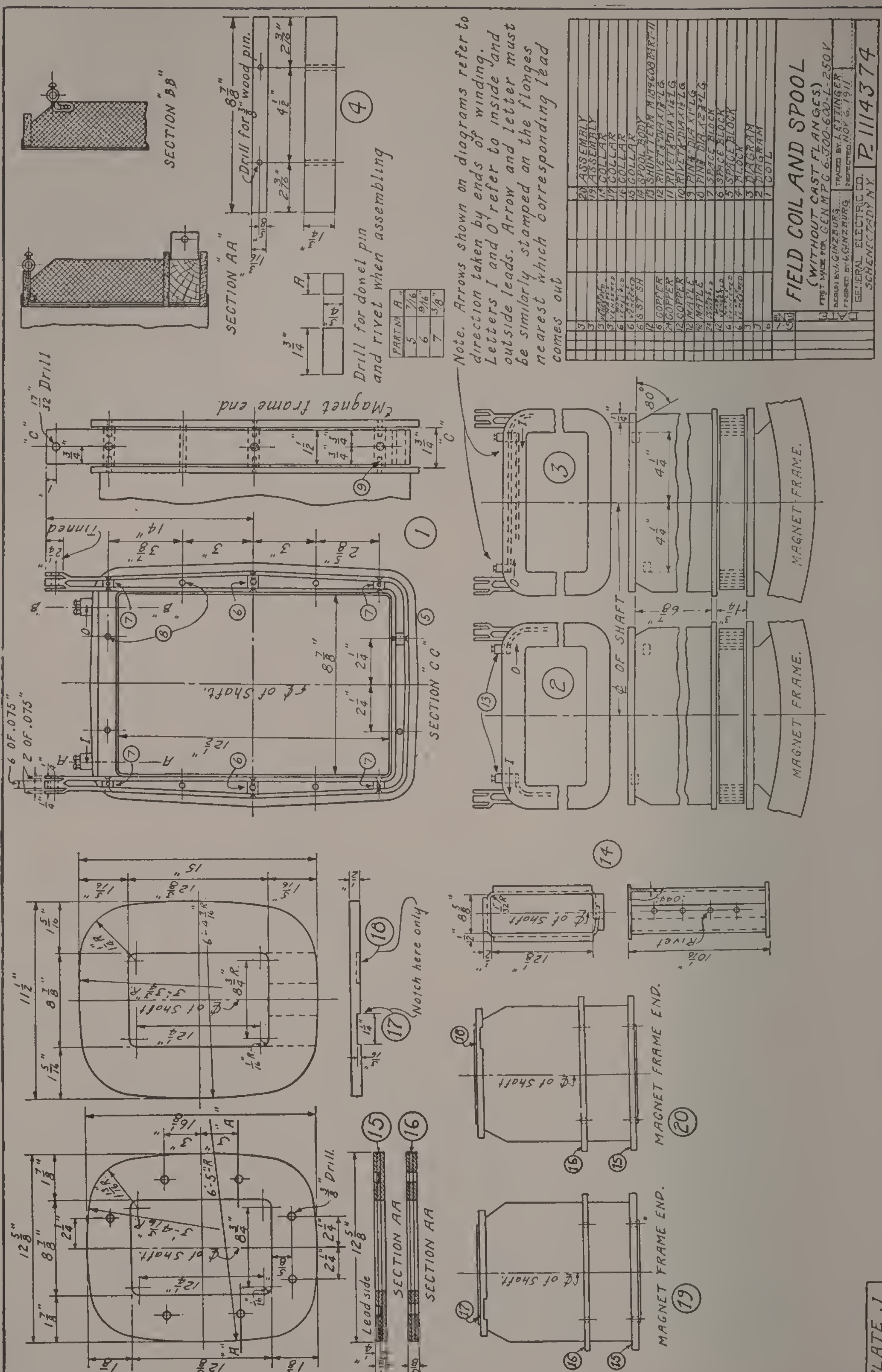
The manner of holding the completed pole piece in place is also interesting. Each lamination has a rectangular hole near the top. When they are assembled, this forms a rectangular passage through the whole pole piece, Fig. 2. Part of the laminations


For 1/2" Rivet.
.0625" Thick.
11 1/4" Polar Arc.
1 5/16" Square hole punched.
1 1/4-7 TAP
1"-8-Tap.
1/4" Drill pins to be staked in firmly
Each shim to consist of 4 sheets, 014" thick.
Each shim to consist of 4 sheets of .014" stock.
12 STEEL C.R. 8 PIN
6 STEEL SH. 7 SHIM
6 STL. FORGIN 6 POLE PIECE COMMUTATING
36 5 RIVET
6 S. STD. SH 4 SHIM
6 STEEL C.R. 3 KEY
6 2 ASSEMBLY
X S. COMM. SH 873567 1 PUNCHING
POLE PIECES
FIRST MADE FOR GEN. M.P.C.-6-300-600-L-250V
BEGUN BY A.B. HOGBEN
FINISHED BY A.B. HOGBEN
TRACED BY HOGBEN
INSPECTED
GENERAL ELECTRIC CO. SCHENECTADY, N.Y.
M873567
PLATE I

also have another hole punched which cuts across the first one and runs out to the top edge so that a square hole is formed from the top into the first hole, shown by dotted line in Fig. 2. Bolts are passed through the frame into these holes and screwed into a threaded key, Fig. 3, placed in the first hole. Thus, when these bolts are tightened up, the pole pieces are drawn up against the frame solidly. In order that there may be some adjustment of the gap between the poles and the armature, shims, Fig. 4, are provided which can be slipped between the frame and the pole pieces, thus bringing the pole piece nearer the armature. These shims are provided with slots instead of holes, so that they can be slipped in after the poles are in place. The air gap can thus be adjusted when the machine is being assembled, without entirely removing the holding bolts.

Commutating Pole Pieces. The pole pieces for the commutating fields are simpler than the main pole pieces, consisting of a rectangular block of forged steel. The corners at the armature end are slightly rounded, Fig. 6. Holes are drilled and tapped in the opposite end for the bolts which hold the pieces to the frame. Shims, Fig. 7, are provided for these pieces the same as for the main poles. Pins placed in the armature end are used for holding the field coils and spools.

Dimensions in Tabular Form. It should be noted that a number of the dimensions on this drawing are given in tables instead of being placed on the drawing itself. The reason for this is one of economy. Any manufacturer making a number of machines of the same general type but of slightly differing characteristics finds that some parts for the machines of different rating vary only in a few dimensions. By placing these variable dimensions in a table a large number of pieces can be covered by the same picture and many drawings saved. Of course, the drawing will not be to scale for more than one of these pieces, but on simple pieces this is not objectionable. The different parts can be distinguished by assigning a specific group number to those parts wanted for any particular machine. This group will be referred to in a general specification covering the machine wanted. Thus in the present machine the specification would call for pole pieces according to a group in a certain drawing. By reference to this group certain pieces


Note. Arrows shown on diagrams refer to direction taken by ends of winding. Letters I and O refer to inside and outside leads. Arrow and letter must be similarly stamped on the flanges nearest which corresponding lead comes out
FIELD COIL AND SPOOL
(WITHOUT CAST FLANGES)
GENERAL ELECTRIC CO.
SCHENECTADY, N.Y.
P 1114374
SECTION "AA"
SECTION "BB"
SECTION "CC"
Drill for donel pin and rivet when assembling
Magnet frame end
MAGNET FRAME
MAGNET FRAME END.
Notch here only
Lead side
PLATE J

would be called for by number; these numbers in turn being given in the dimension table, would fix the dimensions of the piece wanted. This is a method used in many drafting rooms where many similar pieces are used which can be treated in this way.

PLATE J. MAIN FIELD COILS AND SPOOLS

General Details. Having completed the pole pieces, the fields themselves and the spools for supporting them can now be completed. Plate J covers coils and spools for the main fields. These main fields consist of two parts—a series field consisting of a few turns of heavy copper (in this case one turn), which carries the main armature current, and a shunt field consisting of a large number of turns of small wire connected across the armature and carrying a small current. All the electrical characteristics of these coils will be given by the designer—the number of turns for each, the size of copper, and such other things as are fixed by the results to be obtained.

Plan and Elevation of Coils. For the shunt field coils instructions will be given to the winder by specification, since a drawing is not suitable for giving such information. As to the general arrangement of the coils and spool, however, a drawing must be made. Notice the plans and elevation of two complete adjacent poles, Figs. 2 and 3. These show the directions of the windings and the general locations of the terminals. The arrangement of the shunt field terminals is shown in the two sections through AA and BB.

Series Field Coils. The series field, as stated above, must carry the full armature current. The coil, therefore, consists of a number of leaves of copper laid together in multiple and wound around the spool, shown in side and end views in Fig. 1. In order to keep the heating of this coil to a minimum without using too much material, proper provision must be made for ventilation. In this case, this is accomplished by placing wooden space blocks (indicated by small figures *6* and *7*) in such a manner that the coil is divided into two parts and so that there is space for air circulation between the collars and the coil. The two parts of the coil are riveted together through the space blocks. Dowel pins are passed through one of the collars, through the space blocks, and into

recesses in the other collar, so that the coil is held rigidly in place. Since the coil occupies only three sides of the spool, a long wood space block, shown in *Section AA*, is provided to fill the fourth side. This block is held in place in the spool by wood pins the same as the dowels which hold the coil.

Connections must be made to this coil by copper bars. The ends of the laminations are therefore carried past the side of the spool, Figs. 1, 2, and 3, and divided so as to form slots for taking quarter-inch copper bars. The drawing gives the number of laminations in each division and the thickness of each lamination, as well as the dimension of the spaces for the connection bars.

Spools. The spool and flanges are next drawn. The spool proper, Fig. 14, is of sheet steel. The ends are turned over one-half inch to form supports for the flanges; the sides are lapped and riveted. These spools must be made to fit the pole pieces and must have proper dimensions to take the windings with adequate allowance for the flanges.

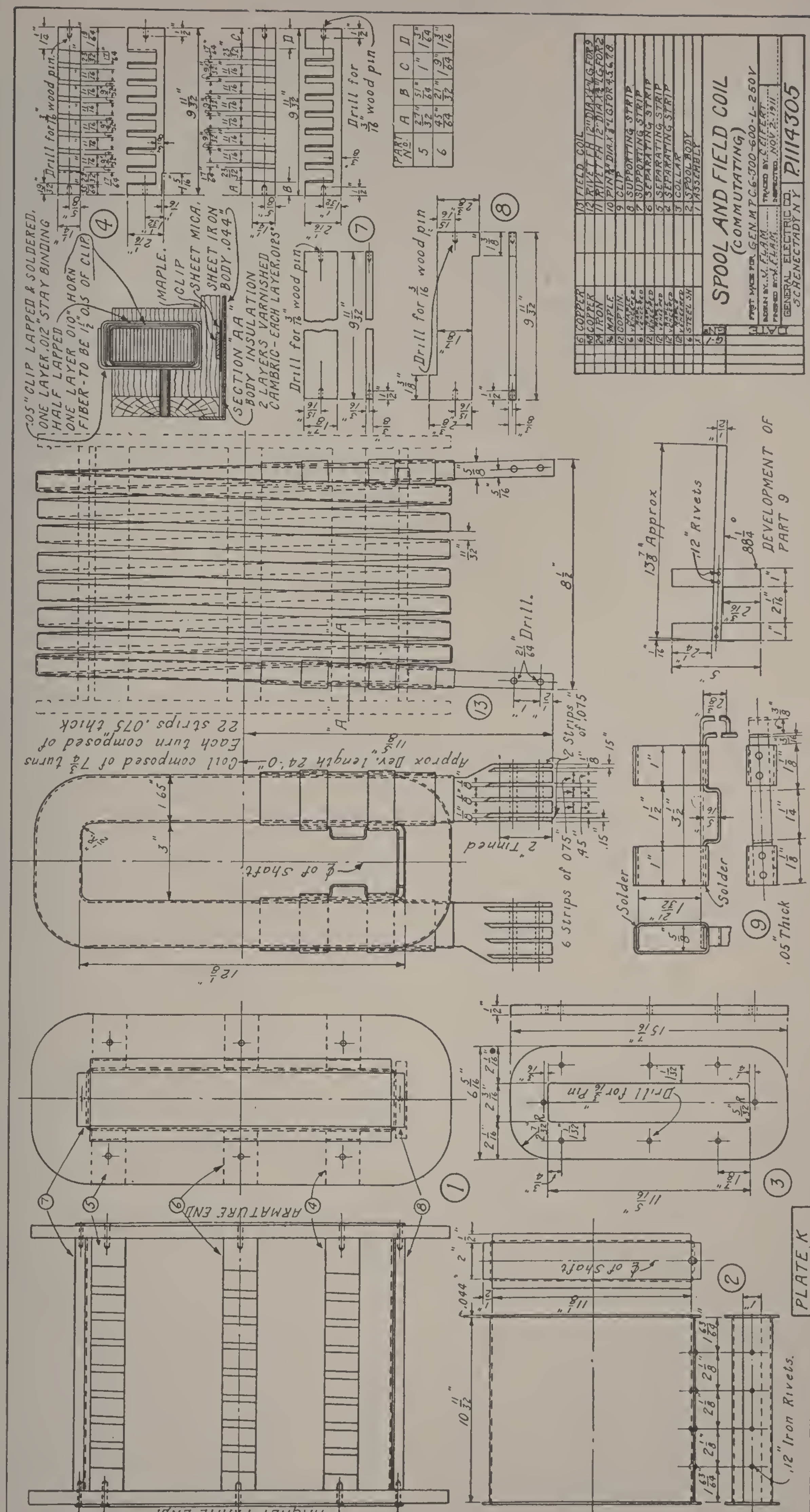
Flanges. The flanges are of veneered maple, to give stiffness and prevent warping. Note that the two flanges enclosing the series coil, Figs. 15 and 16, are identical except in thickness and in the character of the holes for the dowel pins. One plan and two sections are therefore sufficient to show both of these flanges.

The third flange, Figs. 17 and 18, must be different on adjacent poles because of the different location of the terminals. The difference is indicated on the plan and section, however, by showing the location of one notch by full lines and the other notch by dotted lines. This makes the specifications just as clear and saves time.

Assembly of Adjacent Poles. An assembly of two adjacent poles is drawn to show the location of the flanges, Figs. 19 and 20. This is for the benefit of the assembler and is as necessary as the other views of drawings for the man who builds the parts.

PLATE K. COMMUTATING FIELD COILS AND SPOOLS

The commutating fields are connected in series with the armature and carry the full machine current. They are therefore made of heavy copper somewhat like the series section of the main field. Plate K shows these field coils and the spool.


SPOOL AND FIELD COIL
(COMMUTATING)
GENERAL ELECTRIC CO.
SCHENECTADY N.Y.
P1114305
PLATE K
ARMATURE END
MAGNET FRAME END.
Coil composed of 7¼ turns
Each turn composed of
22 strips .075 thick
DEVELOPMENT OF
PART 9
SECTION "A A"
.12" Iron Rivets.

Commutating Coil. The coil is made up of several turns of copper each made up of twenty-two laminations of thin copper strip five-eighths of an inch wide and seventy-five-thousandths of an inch thick, Fig. 13. The coil is insulated by separating the turns with separating strips of veneered maple, shown in the side view, Fig. 1. This veneering, being thin pieces of wood glued together with alternate pieces having the grain at right angles, makes a very stiff firm support, which will not warp or twist out of shape when heated. Placing the coils in this way, they are open to air circulation all over and are easily kept cool. The ends of the coil must be supported firmly from the spool. This is accomplished by means of the two copper clips. Notice *Section AA*, which shows how the coil, clip, and insulation are assembled with relation to each other. Notice also how the ends of the coils are spread to form slots for the connection bars (see left-hand view Fig. 13).

Spool. The spool, Figs. 2 and 3, is similar to that for the main field. The body consists of sheet steel bent to fit the pole piece and having the ends turned down to hold the collars, and the whole held in place by means of rivets in one side. The collars are of veneered maple and are drilled for dowel pins which hold the separating strips. The separating strips, Fig. 4, are also of veneered maple and are very carefully dimensioned to fit the coil. The slots must have the proper slope and each of the strips on one side must be different.

Assembly Methods Considered as Draftsman's Problem. It is possible that one might go over this whole plate without giving a thought to the assembly of the coils. For example, on first thought it might seem proper to wind the coil on the assembled spool. A little thought will show, however, that this would not give a good smooth piece of work and would hardly be satisfactory. It is almost universally true that coils for electrical machinery are wound on forms and assembled afterward. By studying the construction as given in this plate, it will be seen how easy it is to take such a form-wound coil, set the separating strips into place, and slip this down over the spool body which already has one collar in place. The other collar can be placed in position and the ends of the spool body bent down over the top collar.

It is true that this work has nothing to do with shop practice,

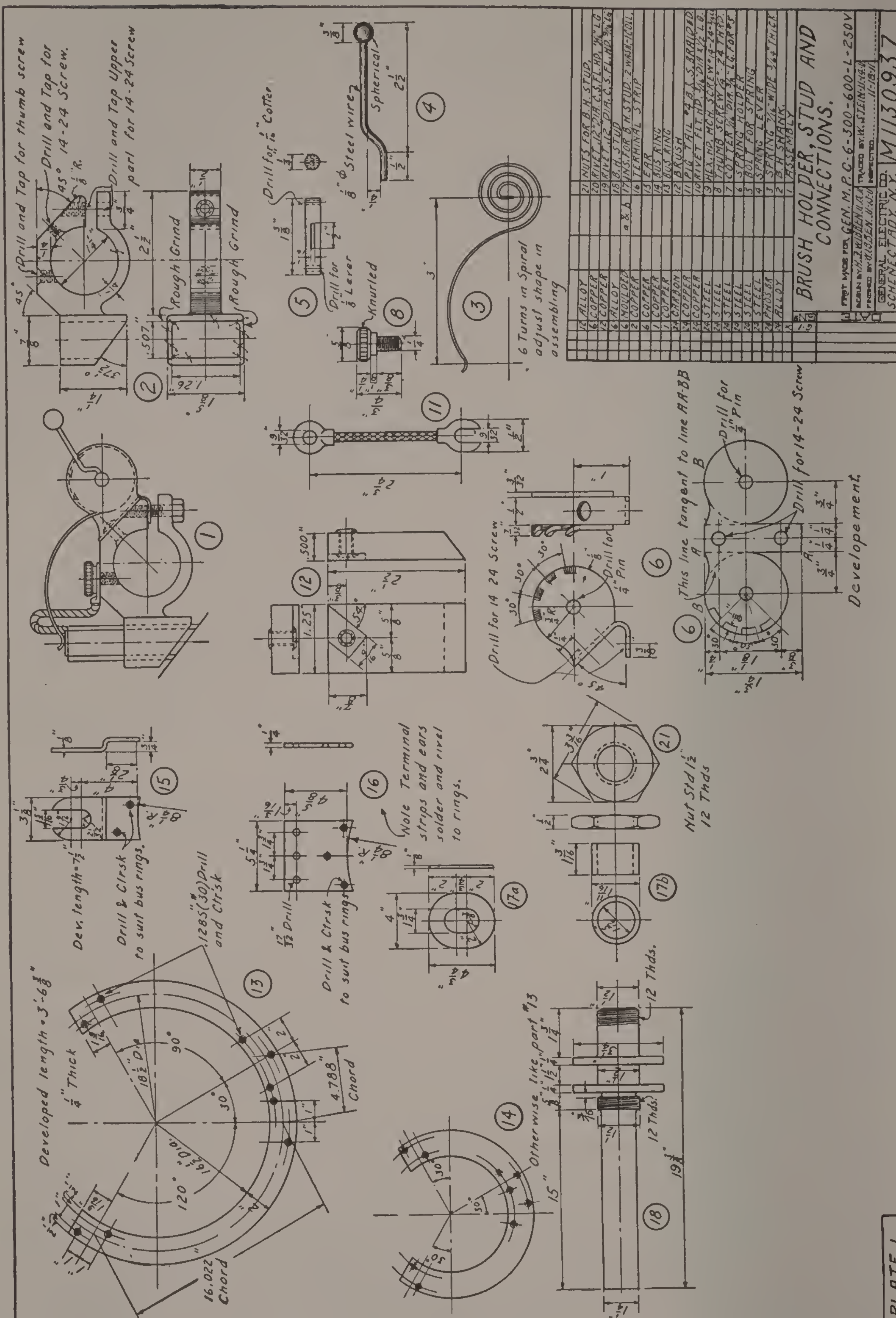
and yet the draftsman must sooner or later attain a position where he sees things from the shopman's viewpoint. The above paragraph illustrates how well the draftsman realized the method to be pursued in assembling these coils. The spool might easily have been drawn so that the labor necessary to assemble it with the coil would have been double that necessary as it is drawn. As an example of what this means, the following is typical: In a certain shop, two similar electrical devices were being made, one for much heavier service than the other. An investigation of costs revealed the fact that the smaller one was costing twice as much as the larger one. Further investigation in the drafting room showed that the whole trouble was that the designing draftsman had laid out the smaller device so that the principal casting was very hard to mold in the foundry and harder still to finish in the machine shop. Simple changes in the drawing by a man familiar with shop methods made the costs of the two pieces comparable. So it will be seen that the draftsman must consider not only the pattern maker, but the foundryman, the machinist, and the assembler as well.

DETAILS OF BRUSH RIGGING

PLATE L. BRUSH HOLDER, STUD AND CONNECTIONS

The previous plates have covered all the principal parts of the machine except the parts for collecting the current from the commutator. Plate L now takes up the details of the brushes and the brush holders. As is usual on such machines the brushes are made of carbon, Fig. 12. The size of the brushes is determined by the designer, as well as the proper number to be used.

Pigtail. The brush must have a "pigtail", Fig. 11, that is, a small cable to connect to the shank of the brush holder in order to get a solid electrical contact between the two. The pigtail is in this case attached to the brush by a copper tube passed through a hole in the brush and through the terminal on the pigtail. Both ends are then spun over, so as to draw the terminal up solidly against the carbon, Fig. 12. In order that the pigtail may clear the spring which holds the brush against the commutator, the slot for it is cut out at an angle. Both sides of the brush are recessed so that the brush can be used until it has gone clear into the holder, due to wear, without interfering with the holding tube or the pigtail.


BRUSH HOLDER, STUD AND CONNECTIONS.
GENERAL ELECTRIC CO. SCHENECTADY, N.Y.
M1130937
PLATE L

The pigtail itself is called for in the title table only, the dimensions of the terminals and over-all length being given on the drawing.

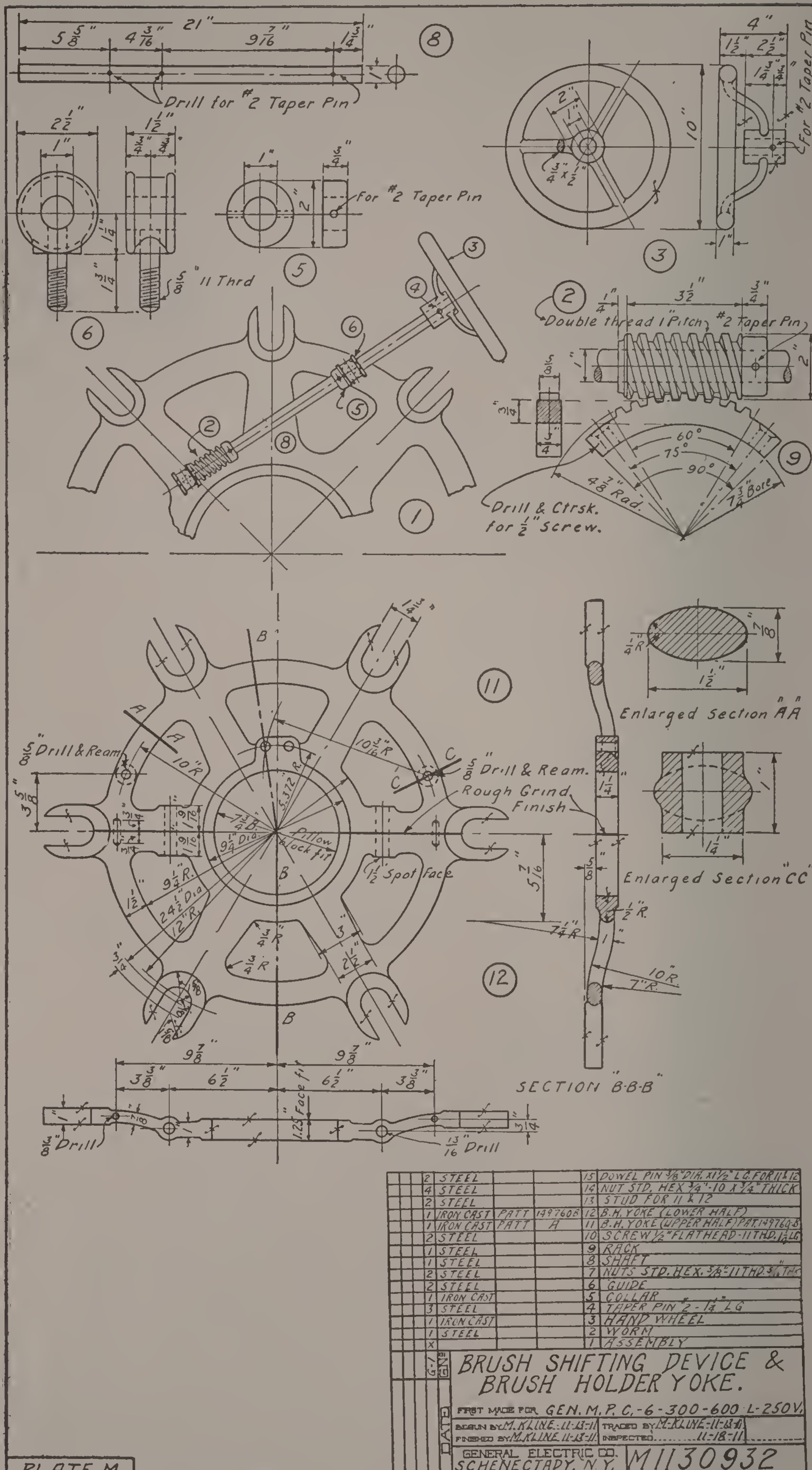
Brush Holder Shank. The brush holder shank, Fig. 2, is an alloy casting. It must be carefully machined in the brush slot, on the face next the commutator and in the hole for the stud. The other surfaces are simply ground to give a smooth appearance. Note how the shank is split so that it can be clamped to the stud by means of a bolt. Tapped holes are provided for the screws which hold the pigtail and the spring holder. The thumb screw, Fig. 8, for the pigtail, not being a standard machine screw, is detailed.

Spring Holder. The spring holder, Fig. 6, is a rather ingenious punching, only the holes for screws and pin being drilled. Note that this piece is shown in its normal shape, but that development is necessary in order that the dies for the punch press can be made.

The pin, Fig. 5, and lever, Fig. 4, for the spring, Fig. 3, are very simple and do not need explanation.

The above discussion of Plate L has covered the brushes and holder completely. Four of these brushes are needed for each pole of the machine, or twenty-four in all. These must be supported over the commutator so as to make proper contact, and the current must be collected from each set and carried to proper terminal strips. The brush holders and the shifting device are taken up in Plate M. The current-carrying parts—the studs and connecting strips—form the remainder of Plate L.

Current-Carrying Parts. *Stud and Insulation Washers.* The dimensions of the studs, Fig. 18, can be determined from the other drawings and from the knowledge that the yoke must be supported from a groove cut into the bearing casting. This stud must be insulated entirely from the yoke. It will be seen that two shoulders are provided. A nut, Fig. 17b, will be used to draw the first shoulder up against the yoke in the slot provided. Molded insulation, Figs. 17a, is placed over the stud between the shoulder and yoke and between the nut and the yoke. The stud can then be rigidly supported by the yoke but thoroughly insulated from it. The other shoulder, with a proper nut, is used for connecting alternate studs electrically by means of the bus rings.



Drill for #2 Taper Pin
For #2 Taper Pin
11 Thrd
For #2 Taper Pin
Double thread 1" Pitch
#2 Taper Pin
Drill & Ctrsk. for 1/2" Screw.
Rad.
Bore
Enlarged Section "AA"
Drill & Ream
Drill & Ream.
Rough Grind Finish
Pillow block fit
Spot Face
Enlarged Section "CC"
Face fit
Drill
SECTION "B-B-B"
2 STEEL — 15 DOWEL PIN 3/8" DIA. X 1 1/2" LG. FOR 11 & 12
4 STEEL — 14 NUT STD. HEX 3/4"-10 X 3/4" THICK
2 STEEL — 13 STUD FOR 11 & 12
1 IRON CAST PATT 149760B — 12 B.H. YOKE (LOWER HALF)
1 IRON CAST PATT A — 11 B.H. YOKE (UPPER HALF) PAT. 149760-B
2 STEEL — 10 SCREW 1/2" FLATHEAD-11 THD. 1 1/2 LG.
1 STEEL — 9 RACK
1 STEEL — 8 SHAFT
2 STEEL — 7 NUTS STD. HEX. 5/8"-11 THD. 5/8" THK
2 STEEL — 6 GUIDE
1 IRON CAST — 5 COLLAR
3 STEEL — 4 TAPER PIN #2 - 1 1/4" LG
1 IRON CAST — 3 HAND WHEEL
1 STEEL — 2 WORM
X — 1 ASSEMBLY
G-7
BRUSH SHIFTING DEVICE &
BRUSH HOLDER YOKE.
FIRST MADE FOR GEN. M. P. C.-6-300-600 L-250V.
BEGUN BY M. KLINE. 11-13-11 TRACED BY M. KLINE-11-13-11
FINISHED BY M. KLINE 11-13-11. INSPECTED 11-18-11
DATE
GENERAL ELECTRIC CO.
SCHENECTADY, N.Y.
M1130932
PLATE M.

Bus Rings and Connecting Lugs. These bus rings, Figs. 13 and 14, consist of copper bars bent into arcs of circles so as to span studs 120 degrees apart. Slotted lugs, Fig. 15, are soldered and riveted to these bars so that these slots will fit over the stud and can be drawn up against the shoulder by nuts. Thus three studs are connected together by each ring. Note that the lugs are offset so that one ring can be assembled with the lugs projecting in one direction, and the other ring with the lugs projecting in the opposite direction. This gives clearance between the bars which will be of opposite polarity.

Terminal Strips. Terminal strips, Fig. 16, are also soldered and riveted to the rings at convenient points so that the external connections can be bolted to them.

PLATE M. BRUSH HOLDER YOKE AND BRUSH SHIFTING DEVICE

Brush Holder Yoke. The brush holder yoke, which is in two pieces, Figs. 11 and 12, so that it can be slipped into the slot on the bearing when the machine is being assembled, is made in the form of a thin wheel with projecting slotted lugs for carrying the studs. These pieces are made of cast iron, and sufficient details must be shown to enable the pattern maker to provide a pattern of proper section at all points. The enlarged sections at the right are for this purpose entirely. Notice on this drawing another example of a bent section line used to save drawing other views. The line BBB is used since it will then take in one of the holes in the hub and permit clearer delineation.

It will be noted that there are two holes in the hub and two in the rim which are for the brush shifting device; the details of the latter must be worked out before the proper location of the holes can be determined.

Brush Shifting Device. It will be noted that the arrangement for shifting the brushes around the commutator, in order to get the proper location for good commutation, consists of a shaft, Fig. 8, having mounted at one end a worm, Fig. 2, which engages the gear or the rack, Fig. 9, mounted on the bearing housing. When the handwheel on the shaft is revolved, the worm shifts the brush holder in one direction or another, until the proper location of brushes is secured. It is necessary, of course, to place

the shaft in such position that the worm engages the rack properly, that is, so that the pitch line of the rack and worm are tangent. The holes in the brush holder yoke can be located as soon as the worm and rack have been laid out; it will be noted that four holes are provided, although only two are necessary, so that the shaft and handwheel can be assembled on either side of the commutator, depending upon which is more convenient for operation.

Worm and Rack. The worm, detailed in Fig. 2, is a good example of the double rectangular thread. In order that the motion may not be too slow a one-inch pitch has been determined upon, but if a single thread were used with this pitch the thread would be entirely too deep; therefore, a double thread is used, which reduces the depth to a reasonable amount. If the drawing is checked carefully, it will be noted that the worm is not drawn to scale, that is, the draftsman has made the picture in the most convenient way and has used proper dimensions. The threads are not detailed, but are covered by a note, giving the number of threads and the pitch. The teeth on the rack are, of course, determined by the pitch of the worm, so that no further information is necessary. It will be noted that the dimensions of the rack are given in degrees, since the amount of the shift required for the brushes would be expressed in this way.

Shaft. The shaft, Fig. 8, for operating the worm is, of course, simply a cylindrical bar of sufficient length to bring the handwheel, Fig. 3, to a convenient point. The only detailed dimensions necessary are those referring to the holes for pins at various points.

For bearings for this shaft a steel casting, Fig. 6, is used, having a stud which passes through the brush holder yoke and is secured by a nut. The shaft is held in the proper position by means of the worm which is pinned to the shaft, Fig. 2, and a collar, Fig. 5, which is also pinned to the shaft and located below the upper bearing. The construction here does not require fine work since the brushes are only shifted at long intervals and easy operation or freedom from friction is not required. The cast-iron handwheel, Fig. 3, is of simple construction, with a hub which fits over the shaft and is pinned to the shaft. The whole construction is simple enough to be easily understood, and great elaboration is not necessary for the workmen in the shop.

BEARINGS AND PEDESTALS

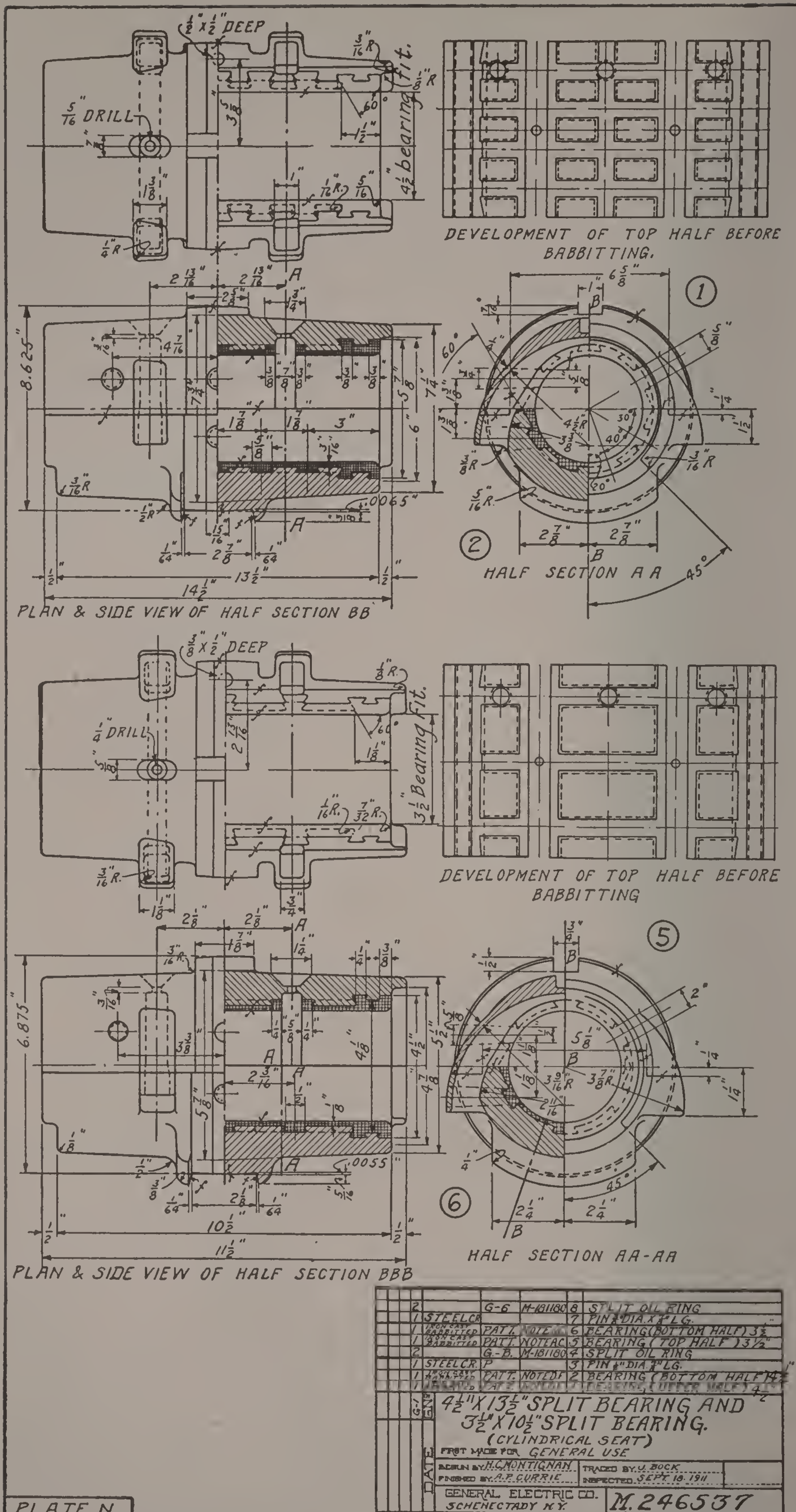
The machine proper, as far as electrical features are concerned, is now complete, although considerable work is still necessary on the connections between the fields and to the terminal blocks at the side of the machine. There are, however, the mechanical features of the bearings and pedestals which are taken care of in the two following plates.

PLATE N. SPLIT BEARINGS FOR ARMATURE SHAFT

General Details. The bearings proper, Figs. 1, 2, 5, and 6, are self-aligning, that is, they are constructed so as to adjust themselves automatically to the position of the shaft. This is accomplished by making the bearing casting with a hub on the outside which is turned to a spherical shape. The bearing pedestal and caps are then constructed so as to fit these pieces into a corresponding spherical support. This makes in effect a ball-and-socket arrangement, which allows considerable adjustment in any direction, so that it is not necessary to align the two pedestals accurately, either horizontally or vertically.

Oil Ring Details. The scheme for keeping oil on the bearings is one commonly used for machines of this class. The oil is contained in the receptacle in the pedestal. The bearings have slots cut through, which arrangement allows oil rings to rest on the top surface of the shaft, the bottom of the ring dipping into the oil in the receptacle. As the shaft revolves, the rings pick up oil and transmit it to the top of the shaft. Grooves are cut in the babbitt metal forming the bearing surface so that this oil can flow over the whole surface of the bearing. It will be necessary, of course, for the draftsman to detail all these parts and to arrange them so that they will be easily constructed in the shop and easily assembled at any time afterward.

Babbitt Metal Linings. It will be noted that the bearings are lined with babbitt metal and that the two halves of the iron shell are cast with ridges so arranged that when the metal is in place it is held solidly with no chance for slipping or turning. This metal, of course, is poured into the bearing with the shaft in place. It will be seen that the openings in the top half of the bearing are so arranged that the babbitt metal can be poured in conveniently.


DEVELOPMENT OF TOP HALF BEFORE BABBITTING.
HALF SECTION A A
PLAN & SIDE VIEW OF HALF SECTION BB
DEVELOPMENT OF TOP HALF BEFORE BABBITTING
HALF SECTION AA-AA
PLAN & SIDE VIEW OF HALF SECTION BBB
2 G-6 M-181180 8 SPLIT OIL RING
1 STEEL CR. 7 PIN DIA. X LG.
1 IRON CAST BABBITTED PATT. NOTE 6 BEARING (BOTTOM HALF) 3½"
1 IRON CAST BABBITTED PATT. NOTE AC 5 BEARING (TOP HALF) 3½"
2 G.-B. M-181180 4 SPLIT OIL RING
1 STEEL C.R. P 3 PIN ½" DIA. LG.
1 IRON CAST BABBITTED PATT. NOTE DF 2 BEARING (BOTTOM HALF) 4½"
4½" X 13½" SPLIT BEARING AND
3½" X 10½" SPLIT BEARING.
(CYLINDRICAL SEAT)
FIRST MADE FOR GENERAL USE
BEGUN BY H.C. MONTIGNAN
FINISHED BY A.P. CURRIE
TRACED BY U. BOCK
INSPECTED SEPT. 18. 1911
GENERAL ELECTRIC CO.
SCHENECTADY N.Y.
M. 246537
PLATE N

It is necessary, of course, to cut away the metal at this point after it is cold in order to provide a peep hole and in order to clear the slots for the oil rings. The inside surfaces, being shaped to fit after the metal is cold, have grooves for oil transmission cut in after the bearing is complete. Since these operations cannot be shown in the drawing, no information is given except as to the metals being used.

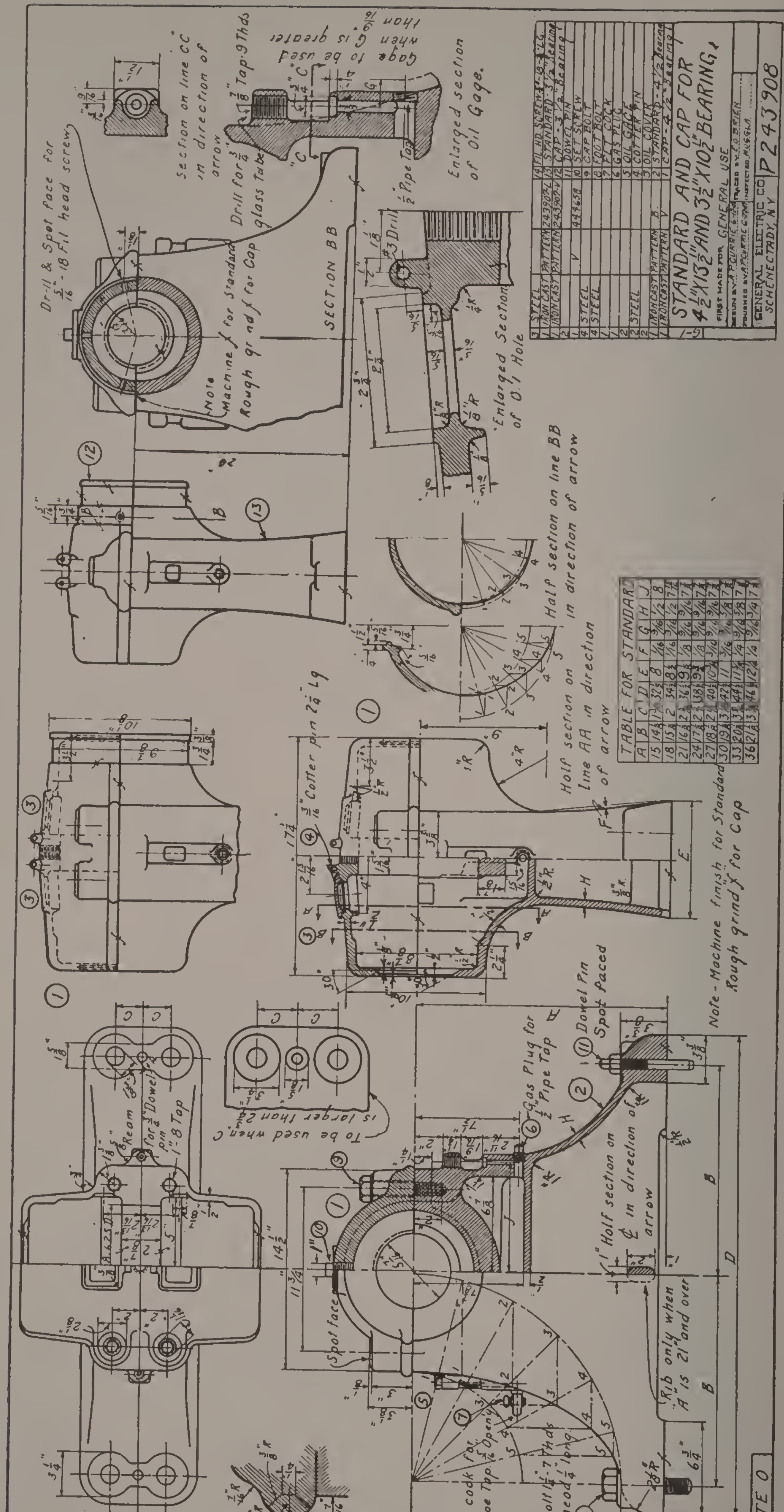
The details of the two bearings are much the same but, nevertheless, they are very carefully brought out in the drawings in order to give the foundryman and shopman the necessary information. The parts of the $4\frac{1}{2} \times 13\frac{1}{2}$ inch bearing are made larger and stronger as this bearing is subject to greater strains, being on the side where the shaft coupling is placed.

PLATE O. PEDESTALS AND CAPS FOR BEARINGS

Pedestal Details. It will be noted, first, that the pedestals or standards, Figs. 2 and 13, are built with machined bearing surfaces at the bottom where they are bolted to the bed plate, or base, which has already been detailed in Plate H. The upper part of the pedestal is cast hollow so as to form a receptacle for oil, an oil gage, Fig. 5, being placed on the outside so that there is constant indication of the oil level.

Bearing Cap. The bearing cap must, of course, be arranged so that it holds the bearing proper solidly in place, and this cap, as will be noted from the plate, Fig. 1, is bolted to the bearing pedestal. Thus, it is an easy matter to remove the cap and open up the bearings at any time. It will be seen that holes, Fig. 3, are provided in the top of the cap, which can be used for inspecting the oil rings to see if they are revolving properly and are carrying oil to the bearings.

Details for Pattern Maker. It will be noted that the castings for the bearings, pedestals, caps, etc., are somewhat complicated, and complete information is given in the drawings so that the pattern maker can make proper patterns and core boxes for producing these castings. A number of half-sections on the main drawings and enlarged sections of cap and foot details, oil gage, and oil holes are necessary for this work in order to show the exact shape of all the different parts of the casting.


STANDARD AND CAP FOR 4½"X13½" AND 3½"X10½" BEARING
GENERAL ELECTRIC CO
SCHENECTADY, N.Y.
P 243908
PLATE O
TABLE FOR STANDARD
SECTION BB
Enlarged Section of Oil Gage.
Enlarged Section of Oil Hole
Half section on line BB in direction of arrow
Half section on line AA in direction of arrow
Note - Machine finish for Standard
Rough grind for Cap
Drill & Spot face for 5/16"-18 Fil head screw
Section on line CC in direction of arrow
Gage to be used when G is greater than 7/16
Gas Plug for ½" Pipe Tap
Dowel Pin
Spot faced
Pet cock for ½" Pipe Tap
Spot face
Rib only when "A" is 21" and over

DETAILS OF ELECTRICAL CONNECTIONS

PLATE P. ASSEMBLY OF CONNECTIONS

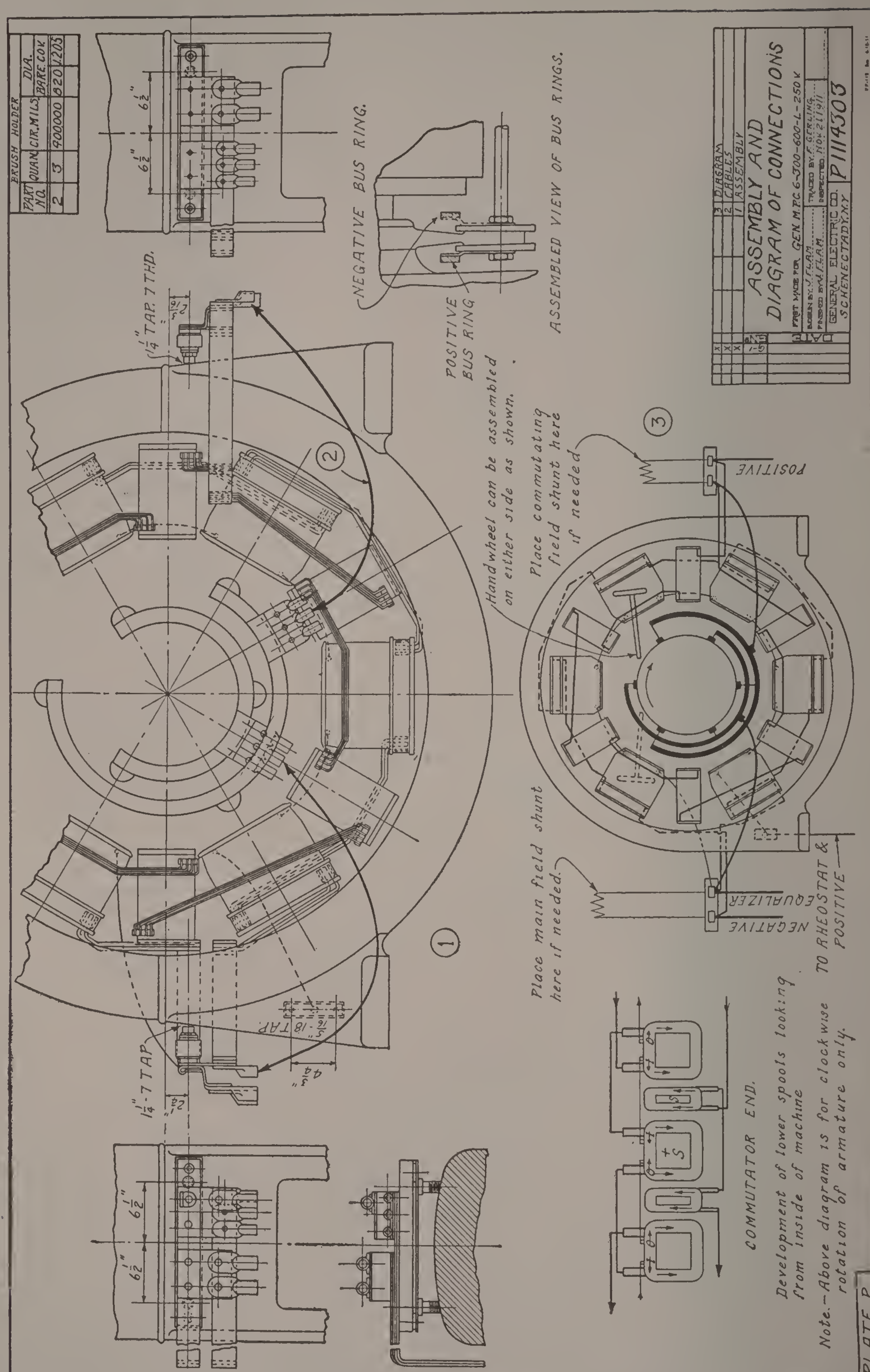
The next work which will be necessary in the drawing room is a layout of the connections between fields and between the bus rings and terminal blocks at the side of the machine. Before the actual layout of these connections can be completed, however, it is necessary to determine exactly how the connections will be made as shown in Plate P.

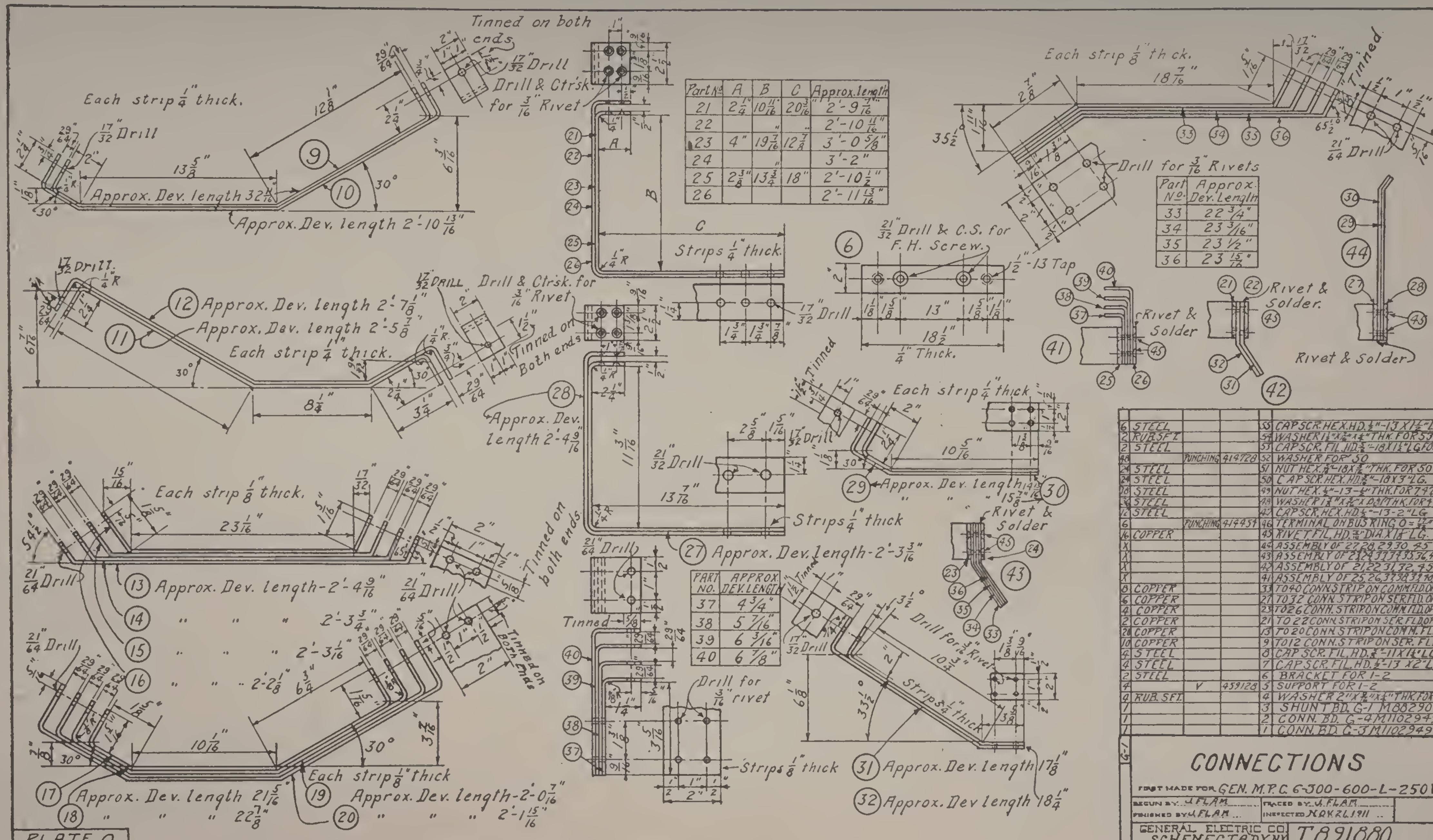
Diagrams of Connections. Fig. 3 shows these connections laid out diagrammatically. An elevation of the machine is drawn rather roughly, showing the bus rings, the fields, the connections between fields, and the terminal blocks with connections to fields and bus rings. Note that the terminal blocks are shown separate from the machine and are revolved through 90 degrees in order to bring them to the same plane as the elevation of the machine itself. This is merely a matter of convenience, so that the connections can all be shown on one view.

Development of Field Spools. Next, a development of the fields is shown at the left, looking from the inside of the machine. This is to indicate the relative location of the series and commutating field connections.

Assembled View of Bus Rings. A small section showing the relative location of the bus rings on each side of the brush holder yoke is also shown so as to indicate the position of these bus rings with respect to the connections. It will be seen that this view and the others just discussed are merely diagrams which are provided in order that the draftsman may have something to start with in laying out the connections.

Assembly Drawing Showing Details of Connections. In Fig. 1, the draftsman has again shown an elevation of the machine and an elevation of each of the terminal blocks on the side of the magnet frame. The detailed drawings of the fields, Plate J, and of the bus rings Plate L, and the amount of current to be carried determine the size and number of bars or cables which should be used for the various connections. The assembly shows the exact shape of these connections and the manner in which the details must be worked out in order that there may be no interference between the various


BRUSH HOLDER
PART NO. 2 QUAN. 3 CIR. MILS 900000 DIA. BARE COV. .820 1.203
NEGATIVE BUS RING.
POSITIVE BUS RING
ASSEMBLED VIEW OF BUS RINGS.
1¼" TAP 7 THD.
5/16"-18 TAP.
Handwheel can be assembled on either side as shown.
Place commutating field shunt here if needed
Place main field shunt here if needed.
POSITIVE
EQUALIZER
NEGATIVE
TO RHEOSTAT & POSITIVE
COMMUTATOR END.
Development of lower spools looking from inside of machine
Note.—Above diagram is for clockwise rotation of armature only.
ASSEMBLY AND DIAGRAM OF CONNECTIONS
GENERAL ELECTRIC CO. SCHENECTADY, N.Y.
PLATE P



CONNECTIONS
FIRST MADE FOR GEN. M.P.C. 6-300-600-L-250V.
GENERAL ELECTRIC CO. SCHENECTADY, N.Y.
T891880
PLATE Q
Each strip 1/4" thick.
Approx. Dev. length 32 1/16"
Approx. Dev. length 2'-10 13/16"
Approx. Dev. length 2'-7 1/8"
Approx. Dev. length 2'-5 7/8"
Approx. Dev. length 2'-4 9/16"
Approx. Dev. length-2'-4 9/16"
Approx. Dev. length-2'-3 3/16"
Approx. Dev. length 21 5/16"
Approx. Dev. length-2'-0 7/16"
Approx. Dev. length 17 3/8"
Approx. Dev length 18 1/4"
Each strip 1/8" thick.
Strips 1/4" thick
Strips 1/8" thick
Tinned on both ends
Drill & Ctrsk. for 3/16" Rivet
21/32" Drill & C.S. for F.H. Screw.
1/2"-13 Tap
1/4" Thick.
Drill for 3/16" Rivets
Rivet & Solder
SHUNT BD. G-1 M882901
CONN. BD. G-4 M1102949
CONN. BD. G-3 M1102949

parts. Note how the cable connections between the bus rings and the terminal blocks have been indicated only by a line with arrowheads; that is, these cables will hang in a loop, and there is no use wasting time or effort in drawing them in completely.

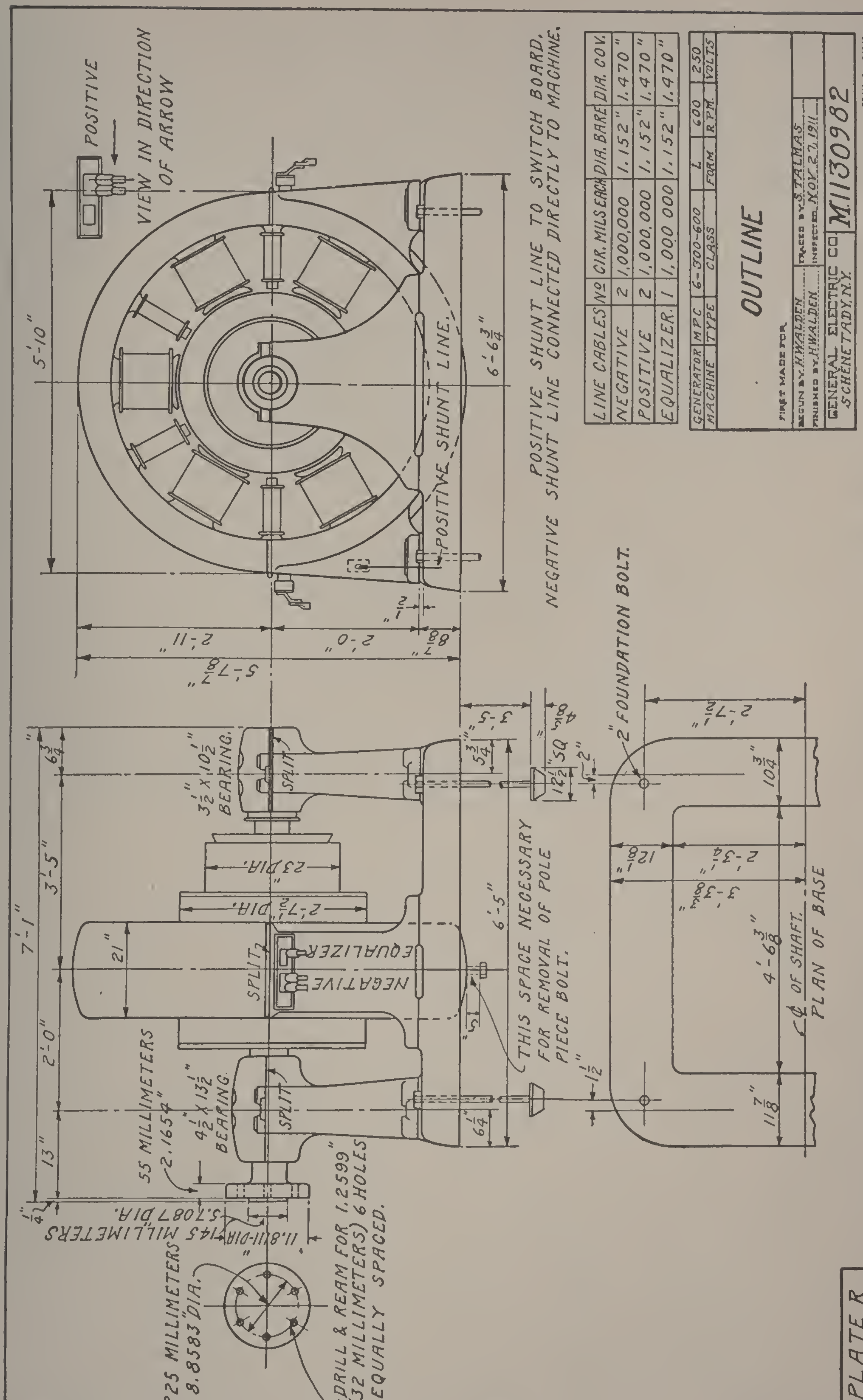
PLATE Q. CONNECTIONS

Having completed the assembly layout of the connections, the details can be worked up as shown on Plate Q. This plate shows each bar of the connections laid out to exact shape and dimensions, and represents a very large amount of tedious work. The draftsman must check with extreme care every dimension given in the previous drawings which will affect the dimensions of these bars, and must be sure in every case that the bars will fit into the proper slots or terminals provided for them on other parts of the machine and will clear all of the fields, the framework, machine, or any other part where electrical or mechanical clearance is necessary. In each case, it is also necessary to determine as nearly as possible the developed length of the bars so that the copper can be cut before bending. The draftsman must also consider the assembler and see that the bars are arranged so that they can be assembled easily and so that the holding bolts can be slipped into place and drawn up without interference. While all of this means an exceptionally large amount of work on the part of the draftsman, it should be perfectly clear to the student just what method has been followed and what work is necessary in developing this drawing.

FINAL ASSEMBLY DRAWING

PLATE R. OUTLINE

General Details. The final plate of this series is Plate R. This is a drawing which is entirely unnecessary from the standpoint of manufacturing the various parts of the machine, but is indispensable to the man who assembles the machine either in the factory or during installation. This drawing is laid out along the same lines as Plate A except that more detail is included and the information given bears in mind especially the assembler. It will be noted that the foundation bolts are shown in this drawing, the location for these bolts being given so that the foundation can be properly


VIEW IN DIRECTION OF ARROW
POSITIVE
POSITIVE SHUNT LINE TO SWITCH BOARD.
NEGATIVE SHUNT LINE CONNECTED DIRECTLY TO MACHINE.
POSITIVE SHUNT LINE.
LINE CABLES | NO | CIR. MILS EACH | DIA. BARE | DIA. COV.
NEGATIVE | 2 | 1,000,000 | 1.152" | 1.470"
POSITIVE | 2 | 1,000,000 | 1.152" | 1.470"
EQUALIZER | 1 | 1,000,000 | 1.152" | 1.470"
GENERATOR MPC 6-300-600 L 600 250
MACHINE TYPE CLASS FORM R.P.M. VOLTS
OUTLINE
FIRST MADE FOR
BEGUN BY H.WALDEN
FINISHED BY H.WALDEN
TRACED BY S.TALMAS
INSPECTED NOV. 27, 1911
GENERAL ELECTRIC CO. SCHENECTADY, N.Y.
M.1130982
2" FOUNDATION BOLT.
THIS SPACE NECESSARY FOR REMOVAL OF POLE PIECE BOLT.
℄ OF SHAFT.
PLAN OF BASE
EQUALIZER
NEGATIVE
SPLIT
3½" X 10½" BEARING.
4½" X 13½" BEARING.
23" DIA.
55 MILLIMETERS 2.1654"
5.7087 DIA.
11.811 DIA. 145 MILLIMETERS
225 MILLIMETERS 8.8583" DIA.
DRILL & REAM FOR 1.2599" (32 MILLIMETERS) 6 HOLES EQUALLY SPACED.
PLATE R

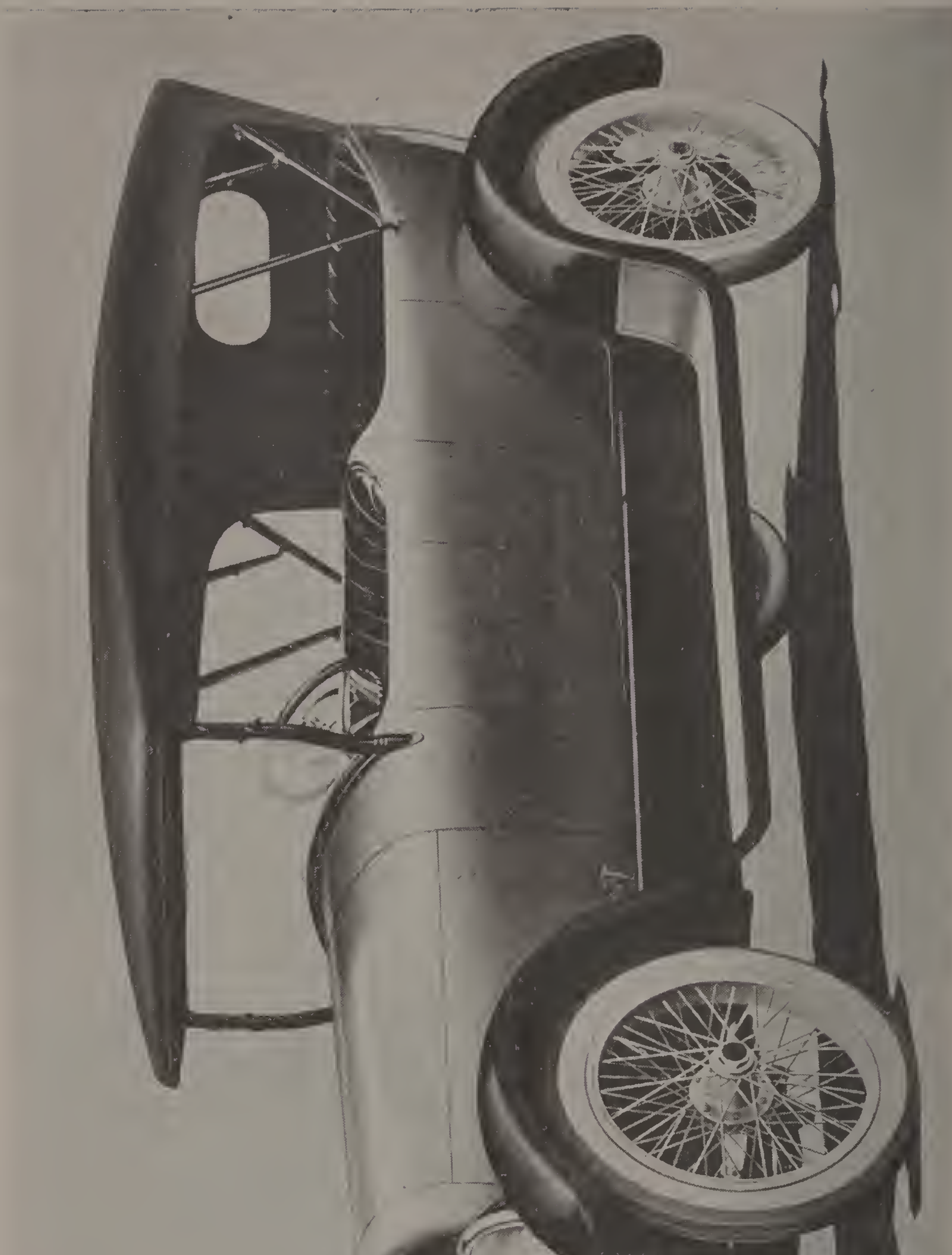
constructed and bolts set, even if the machine had not been received.

Coupling Details. Another point which is given in detail is the coupling for attaching the machine to the prime mover. It will be noted that the dimensions of this coupling have been given in inches taken from the detail drawing, and also in millimeters. This is necessary since the machine may be for use in a country where the metric system is used, and the manufacturer of the prime mover might be familiar with the metric system only.

Terminal Locations. Notice that the relative locations of the terminals are shown and that the terminals themselves are marked definitely, "positive", "negative", and "equalizer". A table is also included which shows the proper size cables for the positive, negative, and equalizer leads. In fact, all the information on this drawing is of such a nature that the drawing can be given to the ultimate user of the machine and can be used by him for assembling and setting the machine on its foundation. It will be seen that very few of the smaller details have been shown, such as bolt heads or holding bolts for the field, etc.; that is, these details are unimportant for such a drawing and would require an immense amount of time on the part of the draftsman. Time spent in putting in these details would be a great waste of money and would add nothing to the value of the drawing.

Missing Information Provided in Specifications. If the student has studied the plates thoroughly, he will see that there is some information which is not given in these drawings. This information, such as the size of wires and number of turns for the shunt fields, is given in the form of specifications. In any electrical device it will be found that some such information cannot conveniently be included in a drawing. It is also true that there must be some sort of master sheet which will connect the many drawings necessary for showing such machinery; that is, the shop specification or summary sheet will be prepared, usually in the form of a table. This may include a list of all the drawings necessary for building the machine and will contain either the specification for such parts of the machine as are not covered on the drawings or a specific reference to another drawing which does contain such specification. In other words, the manufacturer, in placing such

a machine in the shop to be built, will give to the shopman such a master sheet or drawing list from which the shop man may determine exactly what detailed information he must obtain in order to produce the machine. The practice in this respect varies considerably with different manufacturers, but practically all of them use some modification of this plan in order to have something which will connect the various drawings and give proper reference for these drawings to the shopman. The plates which have been shown in this work are for the most part of such a nature that they may be developed independently by the student. Some of them may require a considerable knowledge of the principles of electrical design, but it is to be hoped that the most of them will be developed by the students, since such development will give a better idea and a more thorough grasp of the principles involved than anything which can be written. It should be remembered that the drawings included in this set of plates will show only one method of procedure. This method may be modified to some extent in any drafting room and does not represent any fixed scheme. The general principles of line delineation are followed rather closely and the method represented is in use by a large manufacturer and can be considered as practical and successful.



MARMON SEVEN-PASSENGER TOURING CAR

Courtesy of Nordyke and Marmon Company, Indianapolis, Indiana

GASOLINE AUTOMOBILE CONSTRUCTION

FEATURES OF MOTOR-CAR CONSTRUCTION

GENERAL OUTLINE

Groups and Parts. Practically all modern gasoline motor cars may be divided, in a mechanical sense, into six groups of parts or units. These are: (1) The engine or power producing group; (2) the clutch group, needed, as will be explained later on, with all forms of explosion motor; (3) the transmission, or gearset, for producing the various car speeds and different powers, while the engine gives a practically constant speed and power output; (4) the final drive group, which connects the speed variator or transmission with the rear wheels, and thus propels the car. Of a necessity, this includes the rear axle, while the front axle is usually grouped with the rear; (5) the steering device, for controlling the direction of motion; and (6) the frame, upon which all these and their various accessories are hung, with the springs for suspending the frame upon the axles of the car. There is, of course, a seventh group, the body, but that need not be discussed here, since reference is now had only to the mechanical parts.

Engine Group. In the large diagram of a modern motorcar, Fig. 1, the sectional side view is shown above and the plan view below. In this, note that the engine is placed at the front of the outfit. This is now the general position, practically all modern motorcar manufacturers using it. A few cars have the motor located on the rear axle to save the parts necessary for connecting the two, while formerly the middle position was a favorite one. The purpose of the engine is to generate the power. This is done by the drawing in, compressing, and exploding of gas produced from gasoline.

Carburetion Subgroup. The production of the gas necessitates what is called a *carbureter;* carrying the liquid gasoline necessitates a good-sized *fuel tank*, piping is needed to connect the two; the fuel

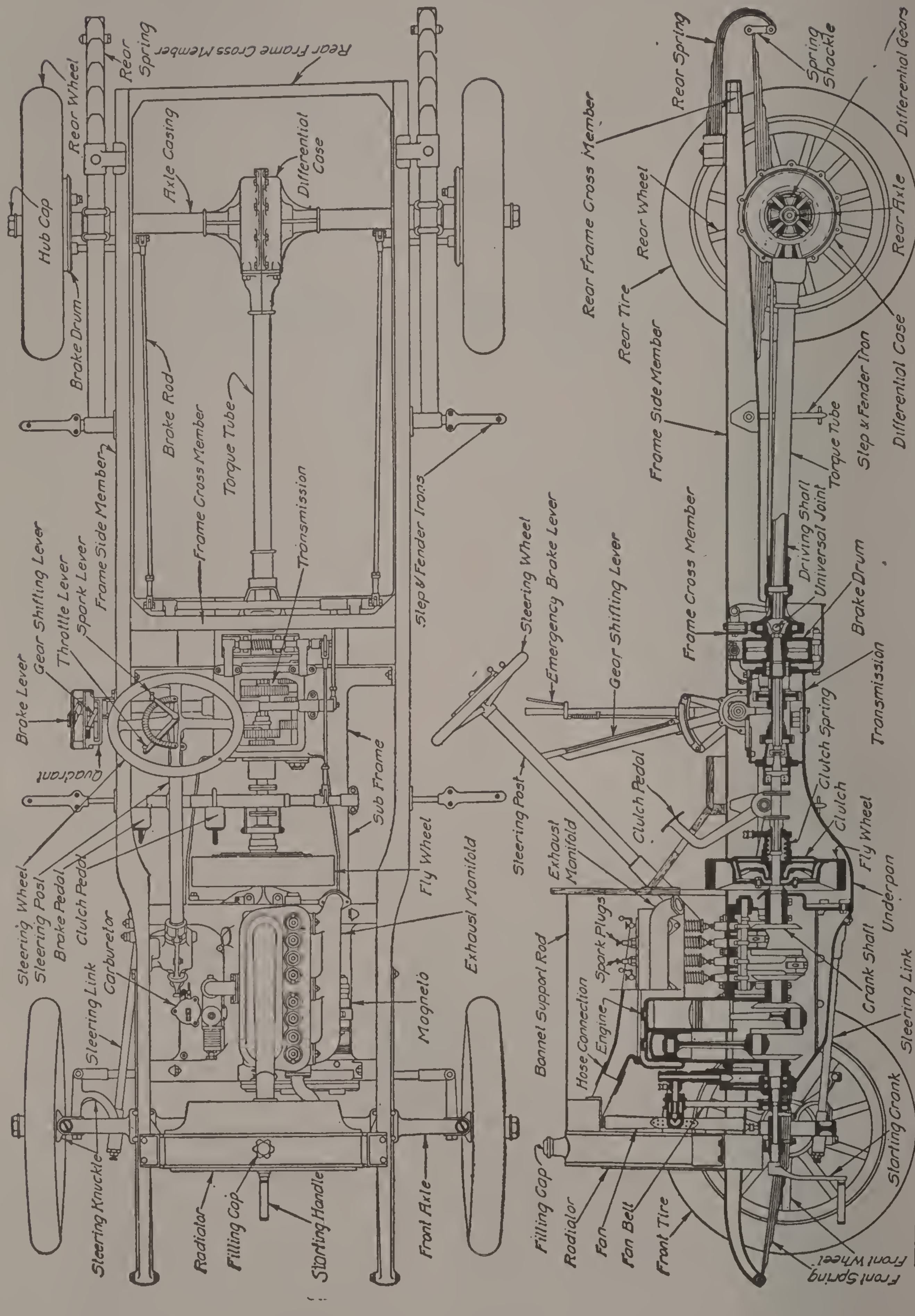


Fig. 1. Side View and Plan of a Modern Motor-Car Chassis, Showing the Various Important Parts, the Location of the Various Groups and Their Interrelations with Other Groups

is not always pure and must be filtered, necessitating a *strainer;* means for turning on and off the supply of liquid must be provided in the form of a cock, while the gas produced is taken into the engine through an *inlet manifold.* These and other parts, the functions and construction of which will be explained in full later on, constitute the carburetion subgroup.

Inlet and Exhaust Valves. In order to get the gas, which is produced by the carburetion group, into the motor cylinders at the proper time and in the proper quantity, there are needed *inlet valves,* and, for their operation, *cams,* which are placed on a *camshaft,* which, as will be explained in detail, is driven from the *crankshaft* of the engine. In addition, after the gas has been admitted into the cylinders, compressed, and exploded, thus producing its power, it is of no further use and must be removed from the cylinders. As this must be done at the proper time, and as the proper quantity must be removed, additional valves known as the *exhaust valves* are needed, these also being operated by cams on a camshaft, driven from the crankshaft.

Exhausting System. Further, in passing out, the exhaust gases pass through a particular pipe, known as the *exhaust manifold,* and thence to the back of the car. As there remains considerable pressure in these gases, when allowed to escape freely, they make much noise and considerable smoke, so that all cars are required by law to carry and use a *muffler.* The name explains the purpose of this—it muffles the noise. The exhaust gases pass through this and thence out into the atmosphere. This whole group of parts might be called the *exhausting system,* for the purpose of removing the gases after use, as contrasted with the carburetion system, for producing and supplying the gases.

Ignition System. In an intermediate stage comes the *explosion.* This is done by means of an *electric spark,* which is produced within the cylinders by means of a *spark plug.* The electric current which is the original source of this spark may be produced by means of a form of rotary current producer, known as a *magneto,* or it may be taken from a *battery.* In any case, such current must be brought up to a proper strength and the various sparks must be produced at the exact time they are needed. All this calls for auxiliary apparatus. Moreover, the current producer, if it be a magneto, must be driven

from some rotating shaft; there must be a suitable place provided on the engine for it, with means for holding it there, as well as for quick and easy removal. All this, as a complete unit, is called the ignition system.

Cooling System. In the production of the gas for use, and in its explosion and subsequent expanding and exhausting, a great amount of heat is created. Some idea of this may be gained from the two simple statements that the explosion temperature often runs up as high as 3000° F., and the exhaust temperature frequently is as high as 1500° F. In order to take away this heat, which communicates itself to the walls and parts of the engine wherever it contacts with them, and by conduction, to other parts with which it does not contact, the parts which are exposed to the greatest heat are surrounded by hollow passages, called *jackets*, through which water is forced or allowed to flow. This might be called a collector of the heat, for it is then conducted to the *radiator*, a device for cooling the water, which is there cooled off and then used again. In order to circulate the water, a *pump* is used, driven from some rotating shaft, supported, removable, accessible, etc. All this, with the necessary piping to connect the various parts, is called the *cooling system.*

Lubrication System. Moreover, as the various parts rotate within one another, *bearings*, or parts specially designed to facilitate easy and efficient rotation, must be used. Furthermore, in and on all such bearings a form of *lubricant* is necessary, as it is also between all sliding parts. In order to have a copious supply at certain points, various forms of *lubricators* or *oil pumps* are needed to circulate it; pipes must be provided to carry it; a *sight feed*, or visible indication that the system is working, must be placed in sight of the driver (usually on the dashboard); an *oil tank* for carrying the supply must be provided; and a location found for the lubricator or pump and means for driving, removing, adjusting, and cleaning it. All this as a whole comes under the head of the lubrication system. This system covers in addition isolated points requiring lubrication, and the different ways used to supply them.

Starting System. In order to start the engine, a *starting handle* is provided on all older cars, with possibly a *primer* working on the carbureter, and other parts. On modern cars, this work of starting is done by electricity, which requires a *starting motor*, a *battery*, a

switch for connecting the two, wiring, buttons, and other parts. All this combined is called the *starting system*.

Flywheel. At one end of the engine shaft, there is provided the flywheel. This is a large, wide-faced member of metal, comparatively heavy, the function of which is to store energy (by means of rotation) as the engine produces it, and to give it back to the engine at other parts of the cycle when energy is needed and none is being produced. In short, it is a storehouse of energy, absorbing the same from the engine, and giving back the excess when it is needed. In general, this effect is greatest when the mass of metal is farthest from the center, consequently flywheels are made of as large a diameter as is possible considering the frame members. Note this in the illustration, Fig. 1,

Clutch Group. Within the flywheel the *clutch* is located, generally. This is a device, by means of which a positive connection can be made with the engine, or disconnection from it effected at the driver's will. A moment's consideration will show that when such disconnection is made with the engine running, it will continue to run idly, and will not drive the car, which, perforce, must stand still. Similarly, when the positive connection is made the motor will drive the clutch and such parts beyond it as are connected-up at the time. This arrangement is necessary because of a peculiarity of the gas or gasoline engine—it cannot start with a load but must be started and allowed to get up speed before any load is thrown upon it. This is the function of the clutch, for at all starting times it is thrown out, disconnecting the balance of the driving system from the engine, so that the latter may speed up. When this has been done, the proper gear is engaged, and the clutch is thrown in so that the engine picks up this load.

Like other parts, this must have a means of connecting and disconnecting, a proper place, proper fastenings, means for adjustment and removal, other means for lubrication, as well as other parts. All this, collectively, is called the clutch group.

Transmission Group. As has just been pointed out, the engine cannot start with a load; it must get up speed first. Furthermore, it must be started under a light load. This necessitates certain *gearing*, so that, when starting, the power of the engine may be multiplied many times before reaching the wheels, and, therefore, before it is

applied to the propulsion of the car. Furthermore, it has been found convenient to have a series of such reductions or multiplications. These correspond to the various speeds of the car, for obviously, if the power is multiplied by means of gearing, it is reduced in speed in the same ratio. This whole group of gearing is the *transmission* or *gearset*, and the various reductions are the *low speed*, *intermediate*, and *high* in a *three-speed gearbox;* and *low*, *intermediate*, *second*, and *high* in a *four-speed gearbox*. A gearbox is always spoken of by its number of forward speeds, but there is in all of them, in addition to the forward speeds, a *reverse speed* for backing the car.

In the usual form, these gears are moved or shifted into and out of mesh with one another, according to the driver's needs. For this purpose, *shifting gears* must be provided within the *gearbox*, that is, the arrangement must be such that the proper gears can be moved back and forth, with a *shifting lever* outside for the driver's use, and proper and accurate connections between the two. The gears must be mounted on *shafts*, these in turn on *bearings*, the bearings must be supported in the *gear case*, and this must be supported on the frame. In addition, there must be suitable provision in the *gear case cover* for inspection, adjustments, and repairs; all the moving parts must be lubricated; all parts must be protected from the dust, dirt, and moisture of the road, etc. All this comprises the *transmission* or *gearing group*, which properly ranks second to the engine group in importance. That is, next to producing the power quickly, efficiently, and cheaply, it is important to use it with equal quickness, efficiency, and cheapness.

Final Drive Group. *Driving Shaft.* The connection from the transmission to the rear axle in pleasure cars is usually by shaft, called the *driving shaft*. On the majority of motor trucks, however, it is by means of *double side chains*, which will not be discussed here. This shaft is generally inclosed in a hollow *torque tube*, with suitable connection at the front end to a frame cross member, and at the rear to the *axle housing*. Its construction is generally such that it contains a *bearing* for the driving shaft at both front and rear ends. In addition, the majority of final drives contain at least one *universal joint*, and many of them contain two. As its name indicates, this will work universally, that is at any angle, its particular function in the driving shaft of an automobile being to transmit power from a horizontal

shaft—that of the engine clutch and transmission—to an inclined one—the driving shaft—with as little loss as is possible.

Rear Axle and Differential. The driving shaft drives the rear axle through some form of gear, either *bevel*, *worm*, or other variety, and is usually a two-part shaft. The reason for cutting the rear axle, is that each wheel must be driven separately in rounding a curve, for one travels a greater distance than the other. This seemingly complicated act is produced by a simple set of gearing called the *differential*, which is located within the driven gear in the rear axle. Each half of this is fixed to one part of the *axle shaft*. All these gears and shafts must have bearings, lubrication, means for adjustment, etc. On the outer ends of the axle shafts are mounted the *rear wheels*, which carry some form of *tires* to make riding more easy. The *brakes* are generally in a hollow drum attached to the wheels. All this goes to make up the *driving system.*

Steering Group. The front wheels perform a different function. These are so hung on the *steering pivots*, that they can be turned as desired to the right or the left; in order to have the wheels work together, a rod, called the *cross-connecting rod*, joins them; while the motion is imparted to them by means of another rod, called the *steering link*, which joins the *steering lever* or *arm* with the right-hand (or left-hand as the case may be) *steering pivot*. The last-named lever projects downward for this purpose from the *steering-gear case*, being itself moved forward and back by the rotation of the *steering wheel* in the driver's hands.

The transformation of the rotation or turning motion of the hand wheel into a pushing (or pulling) or longitudinal movement is accomplished within the steering-gear case by means of a worm and gear; a worm and partial gear; or, in some cases, a pair of bevel gears. All these parts need more or less adjustment, lubrication, fastening means, etc., the complete group being designated as the steering group.

In addition, the steering wheel and post carry the *spark* and *throttle levers*, with the rods, etc., for connecting them to the igniting apparatus (magneto, timer, etc.), and the carbureter, respectively. The purpose of the spark lever is to allow the driver to vary the power and speed of his engine by an earlier or later spark, according to his driving needs. Similarly, the throttle lever is for the purpose of opening or closing the throttle in the intake manifold of the carbu-

retion system, allowing in this way more or less gas to pass to the engine, and thus increase or decrease its power output or speed. Actually, these are parts of the ignition and carburetion systems, respectively, but they are usually grouped with the steering, because located on the steering wheel and post.

Frame Group. Little need be said about the frame. The *side members* generally carry at their front and rear ends the *springs*, which are connected to the axles, and thus support the car. The *front cross member* usually supports the radiator, and sometimes the front end of the engine, too. The *rear cross member* usually supports the gasoline tank, when a rear tank is used. The other cross members may support engine, transmission, shifting levers, or other parts according to their location. In general, the number and character of frame cross members are slowly changing, the modern tendency being toward their elimination. By narrowing the frame at the front, the engine can be supported directly on the side members. With the units grouped, the same is true of the other important units.

Formerly, practically all motors and transmissions were supported on a *subframe*, but it has been found that the same results can be obtained and this extra weight and work eliminated. Consequently, although the drawing, Fig. 1, shows a subframe, these are not as widely used as was the case formerly.

When the shifting levers are placed on the outside, these are fastened to the frame; the steering gear is always attached to it; the headlights generally are supported from the frame; all step, fender, and body parts are attached to it; the *under-pan* for protecting the mechanism from road dirt is attached directly to it; the body, of course, is fastened to it—in fact is constructed with this idea in view—six bolts being used, generally; the muffler previously mentioned is usually hung from a rear-frame member; when electric lighting and starting are used, the battery is most often hung in a cradle, supported by the frame, while the *hood* or *bonnet* is supported equally by the side members of the frame (usually covered with wood) and a rod running from radiator to dash.

In Fig. 1 it will be noted that the engine group (1) and the clutch group (2) are together, really forming one unit. Back of this the transmission (3) and the rear axle or final drive group (5) form two separate additional units. When the transmission is united with the

motor (forming a *unit power plant*), or with the rear axle, one unit is practically eliminated. The different functions of the components are not changed, but the grouping previously pointed out becomes less apparent, for units (1), (2), and (3), or (3) and (5) become one, as the case may be.

ENGINE ELEMENTS

The principles of engine design and the methods and details of engine construction are certainly, in interest and importance, second to none of the other factors that combine to produce the complete modern automobile.

How automobile engines operate, the reasons underlying the various details of different designs, and the relative merits of different constructions are all too little understood by the generality of those who have to do in a practical way with the new conveyance.

Cycles of Engine Operation. In all motors, of whatever sort, and of any type whatever other than those in which there is a perfectly continuous development of the power through constantly rotating elements—as in the electric motor and the steam turbine—there must be reciprocating elements that function through indefinitely repeated series of operations. Such a series of operations is termed the cycle of the engine, as is abundantly explained elsewhere herein, so it will suffice here to call attention to some of the merits and demerits of the different cycles that are in practical use.

Two-Cycle Engines. That type of internal-combustion engine in which every stroke in one direction is a power stroke affords a maximum of power impulses to any given number of engine revolutions, but because of other limitations it is not always possible to make a two-cycle engine run as fast as a four-cycle, so that in the generality of cases the number of explosions in a given period of time, or for a given vehicle speed, is no greater with a two-cycle than with a four-cycle engine.

In addition to this, most two-cycle engines are often difficult to start, apt to be wasteful of fuel, not at all flexible in the matters of speed and pulling power, and in various other respects difficult to apply to automobile service. Their greatest merit is their extreme simplicity.

Four-Cycle Engines. The four-cycle engine is the type by

which nine hundred and ninety-nine out of every thousand of present-day automobiles are propelled. Varied through an immense number of possible forms, and with minor differences in the product of every maker, its fundamental functioning has nevertheless proved so far the most suitable for automobile propulsion.

With the succession of suction, compression, explosion, and exhaust strokes afforded by the four-cycle motor, there is secured a very positive and reliable functioning, and by the expedient of a sufficient cylinder multiplication to afford good mechanical balance and frequent power impulses, its flexibility, durability, and practical

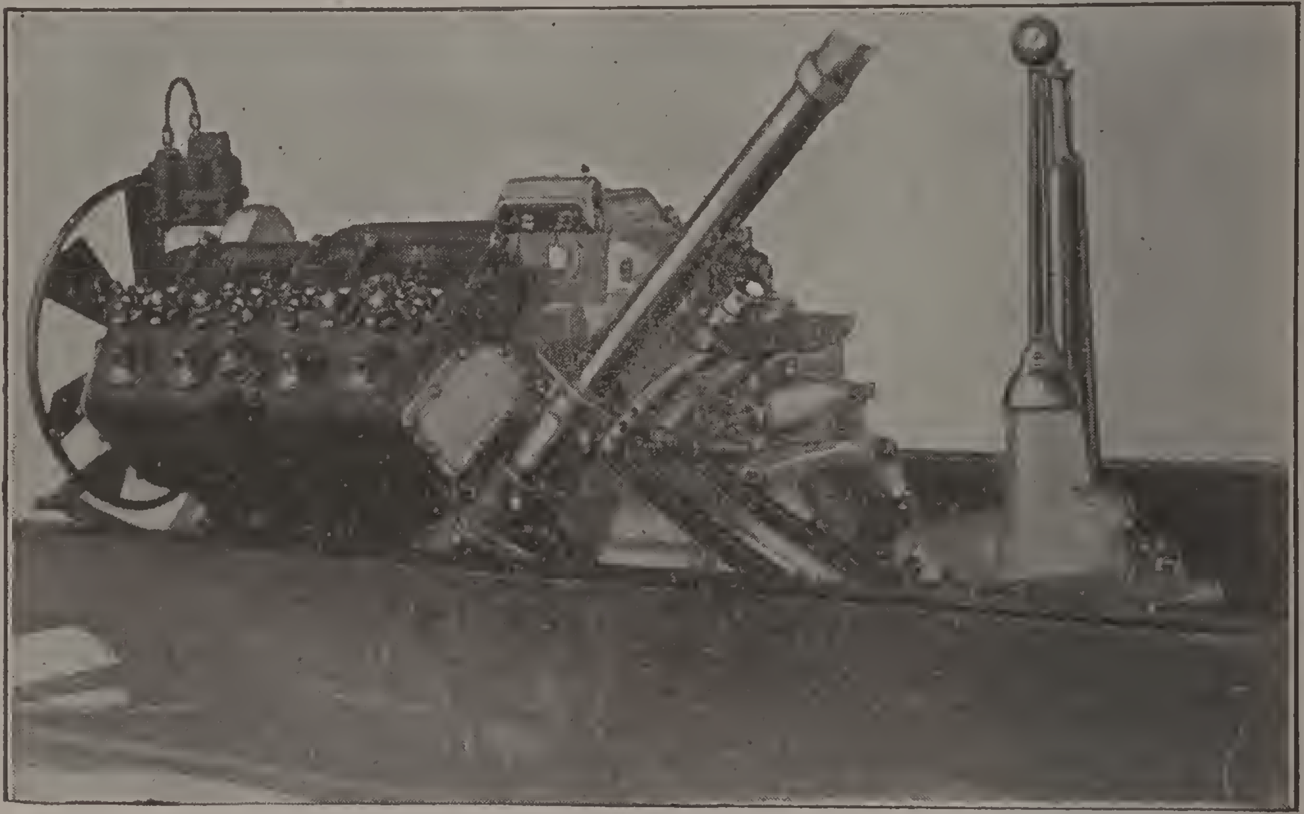


Fig. 2. Eight-Cylinder V-Type Motor of the Latest Cadillac Car Shown Installed in the Chassis

quality in every respect can be brought to very high standards in a well-designed and honestly built motor.

At the same time, the fact that so much more attention has been paid to the four-cycle motor than to any of its possible competitors for popular favor undoubtedly accounts in some measure for its present pre-eminence, and it is an open question with many engineers as to just what virtues might or might not be realized with other constructions were they as exhaustively experimented with and exploited.

Cylinder Multiplication. There seems no reasonable limit to the extent to which cylinder multiplication can be carried, in the effort to improve the mechanical balance and to even the torque of

gasoline motors, but established practice has, nevertheless, settled upon four-cylinder vertical engines as those most suitable for the propulsion of the average automobile—this being the least number of vertical cylinders with which mechanical and explosion balance can be secured.

The use of six cylinders, with the crank throws 120 degrees apart, and the explosions occurring once for every 120 degrees of crankshaft rotation, affords a smoother-running motor than the four-cylinder.

Still better than the "six" from every standpoint but that of cost, which has prevented its wider application to automobiles, is the

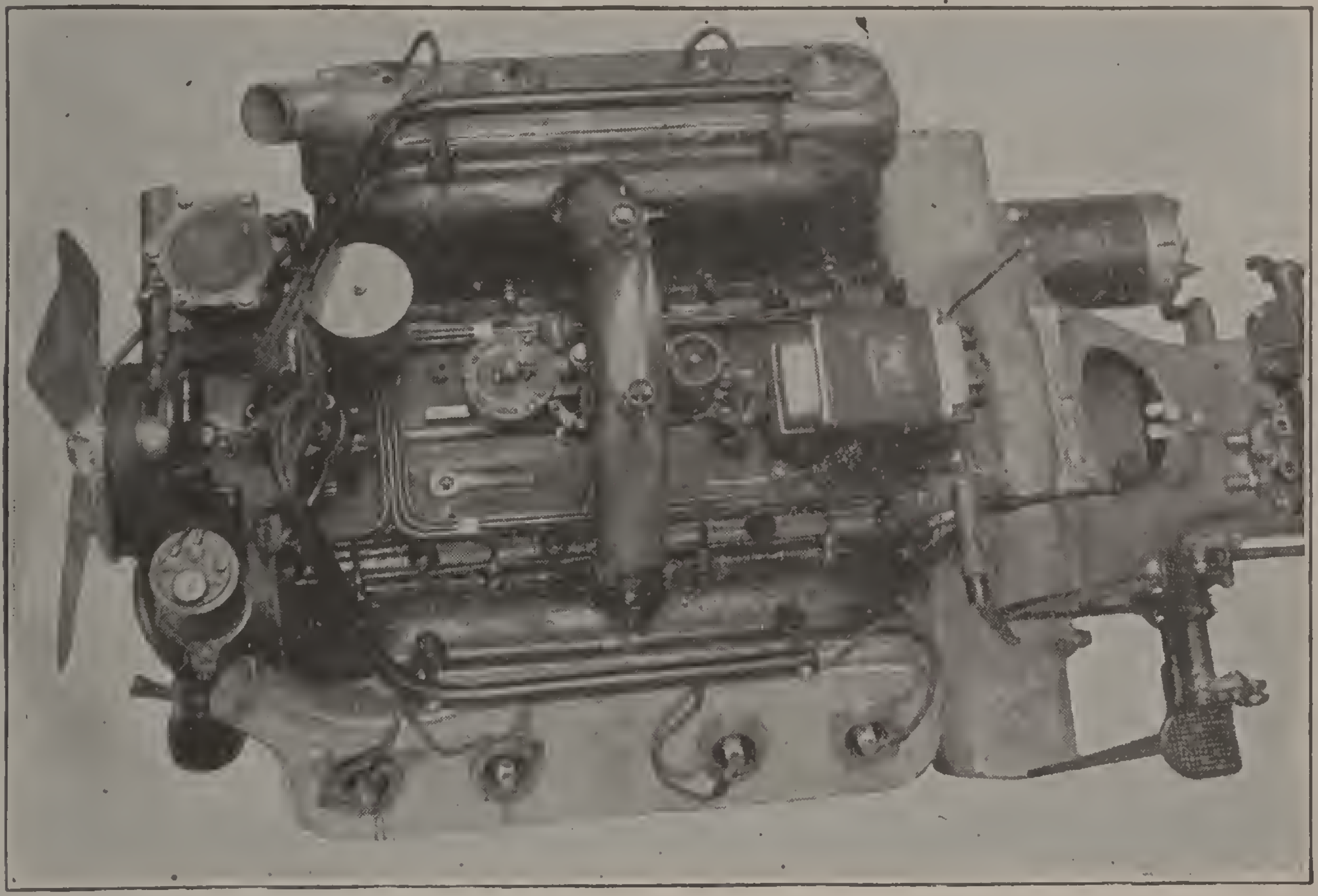


Fig. 3. Overhead View of Stearns-Knight Eight-Cylinder Sleeve-Valve Motor
Courtesy of F. B. Stearns Company, Cleveland, Ohio

V-shaped, eight-cylinder motor, of the type illustrated in Fig. 2, which gives a good view of the unit power plant of an equally well-known American machine. In both of these, there is used a four-throw shaft, similar to the ordinary four-cylinder crankshaft—which is much cheaper to manufacture than a six-cylinder crankshaft—and the two rows of cylinders, each practically constituting a separate four-cylinder engine, are made to work upon the common crankshaft at 90 degrees apart.

The most recent tendency in car motors is toward the eight-cylinder V-type, following the marked success of this form in aviation use.

Not only has the V-form been produced in the poppet valve form but also in the Knight sleeve-valve type, an example of which is shown in Fig. 3. Furthermore, a considerable number of twelve-cylinder V-type motors have been built, a good example being seen in Fig. 4.

In aviation work, no form of motor has made as great progress as the rotating cylinder type, which has been built usually with an odd number of cylinders, as five, seven, or nine; or when these are paired with an even number, as ten, fourteen, or eighteen. As yet, this type has not been applied to motorcars, but, considering its

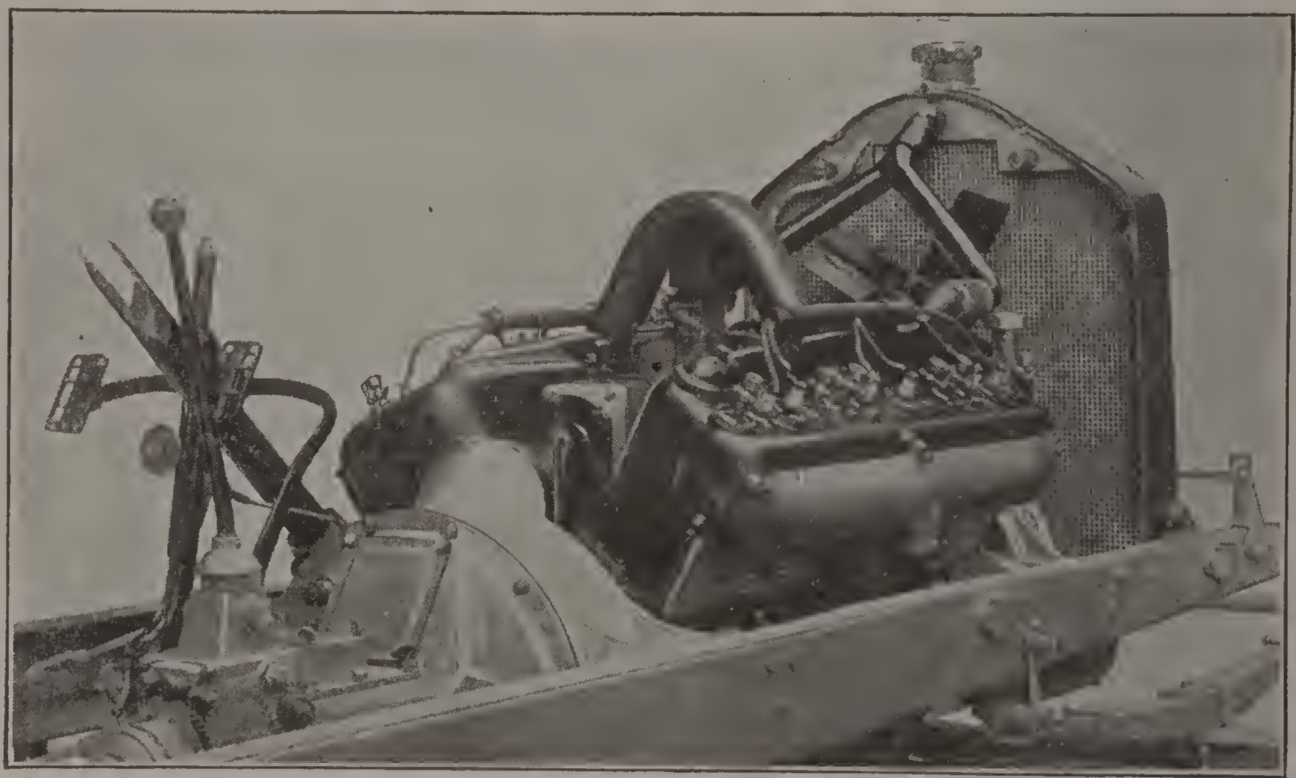


Fig. 4. Side View of National Twelve-Cylinder V-Type Motor
Courtesy of Motor Vehicle Company, Indianapolis, Indiana

advantages, it would not be strange to see this done at an early date. These motors have a single throw crankshaft of very light weight; the rotation of the cylinders at a rapid rate allows of their being air-cooled and also very light in weight, eliminating all parts and weight in the cooling system; the large revolving mass does away with the need for a flywheel, while the practical elimination of reciprocating parts reduces vibration to a minimum.

In the extreme, motors of the V-type have been constructed with sixteen cylinders, eight in each group. These have been very successful in aeroplanes and motorboats, particularly the latter.

Cylinders. Gasoline-engine cylinders are variously made of cast iron, cast and forged steel, aluminum alloys, and other materials.

For durability, and the ability to withstand high temperatures without warping, nothing has been found superior to cast iron, though the lightness of steel and aluminum alloys has commended them for aviation use, and in some cases for racing automobiles.

Cast Separately. Early and still common practice in the building of multicylinder gasoline motors was the casting of cylinders separately, it being by this policy easier to secure sound castings, simpler to machine and finish them, and less troublesome to disassemble parts of the motor without disturbing the rest.

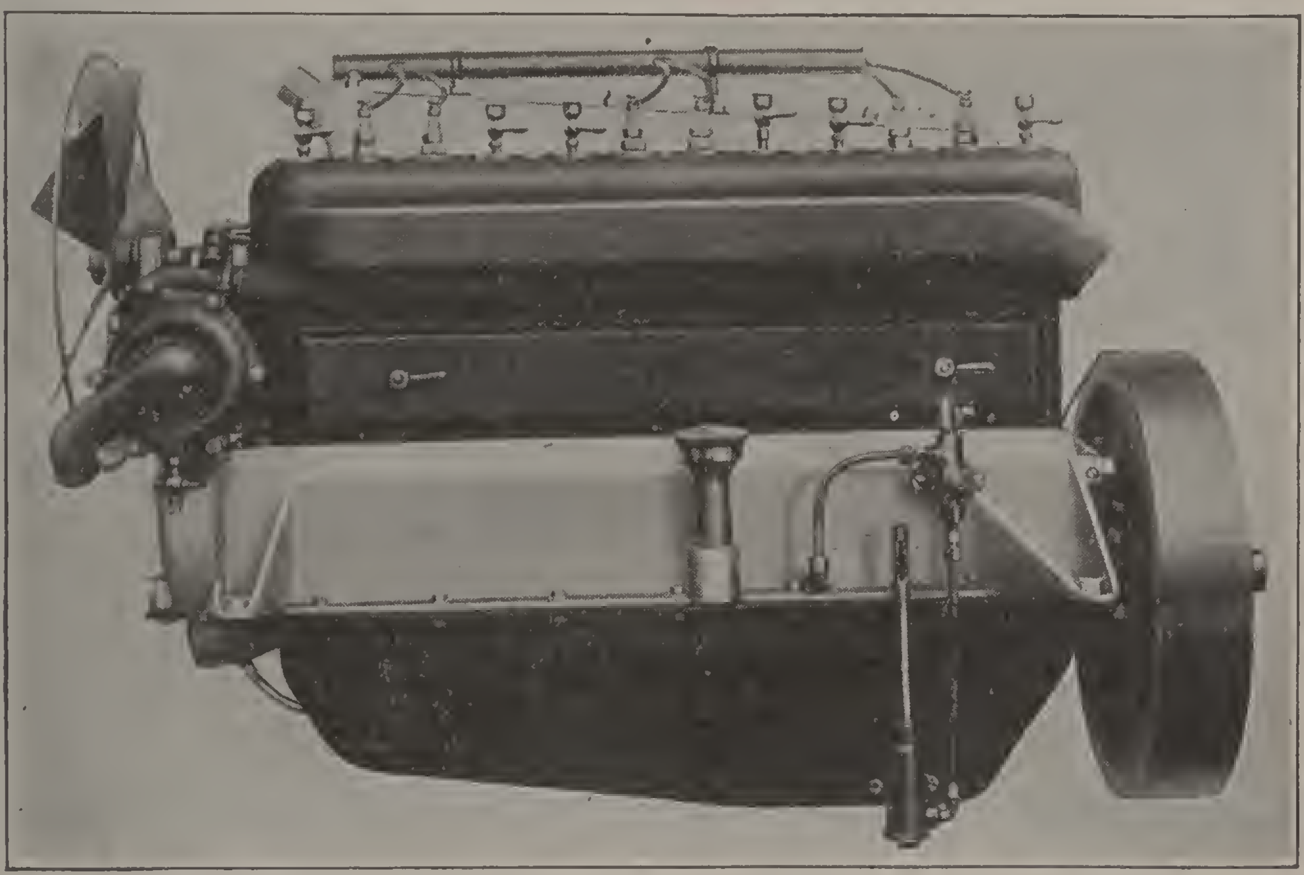


Fig. 5. Studebaker Six-Cylinder Motor Showing the Block Castings of the Six Cylinders

In a number of cases, where extremely light weight was desired, this method was followed but the cylinders were machined all over and a sheet-copper water-jacket was applied in assembling. This has been most successful in aeroplane work, and also for motorcars, but when the Cadillac changed to the form shown in Fig. 3, this construction lost its principal American adherent. In addition to this construction, there have been a number of motors built with an applied water-jacket of sheet metal, this being of the built-on form. These have shown splendid cooling abilities, but, under the twisting and racking of automobile frames, particularly in later years with the more flexible frames, have shown too much tendency toward leakage to become popular.

Cast Together. The great advantage of having the several cylinders of one motor cast together—*en bloc,* as the French term it—is that the alignment and spacing of the different cylinders is thus rendered absolute and permanent, regardless of any differences in adjustment that may otherwise occur in assembling.

This construction has been applied to a large proportion of the small and medium-sized fours, a fair proportion of the larger fours, and to a considerable number of sixes. One of the latter is shown in Fig. 5, this being the Studebaker six, which has a bore of $3\frac{1}{2}$ inches and a stroke of 5 inches, rating at 29.6 horsepower but actually developing about 60. Some idea of the extent of this practice may be gained from the statistics for 1914, these showing that in a total of 236

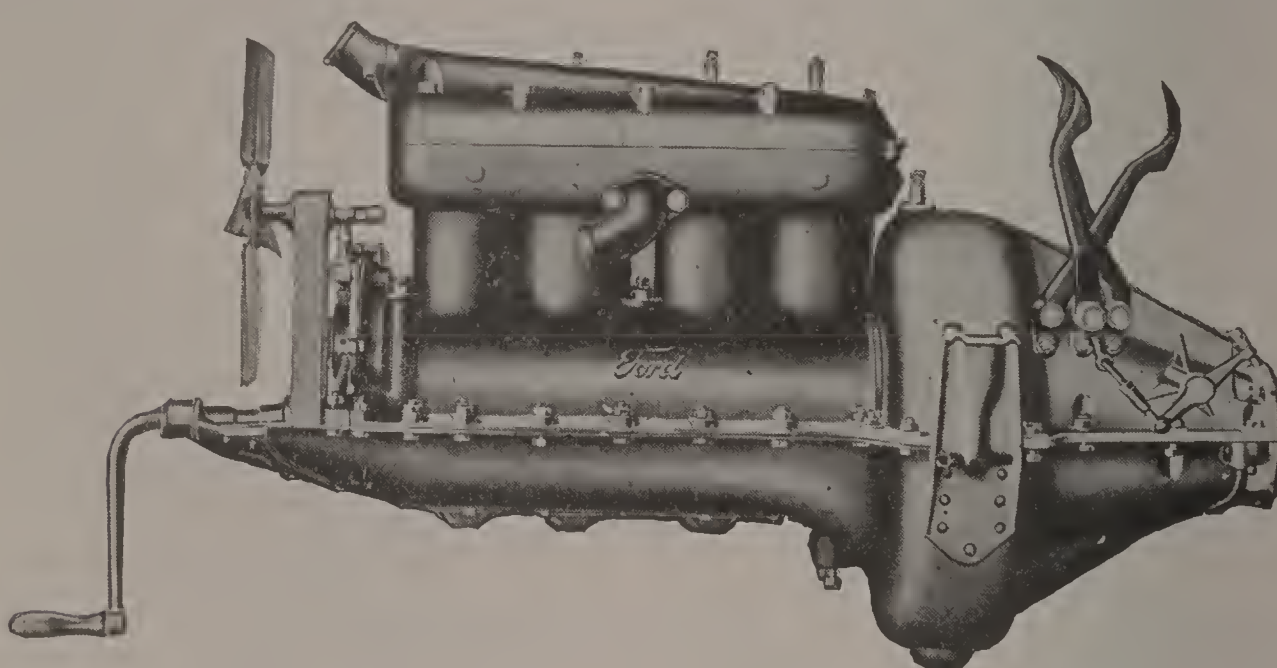


Fig. 6. Ford Engine with Cylinders, Crankcase, and Gearbox in Two Parts
Courtesy of Ford Motor Car Company, Detroit, Michigan

different motors 30 were cast in threes and 93 in block. As the three-cylinder construction is really a block modification, this gives a total of 123 as compared with the individual casting, 15, and the twin, 98.

Another advantage is that the water connections, exhaust and intake manifolds, etc., are rendered simpler both in their form and the number of their points of attachment.

In some advanced motor designs the passages for the incoming mixture and the exhaust gases, and in one case even the carbureter itself, are all incorporated in the main casting.

Another example of simple construction is that illustrated in Fig. 6, which depicts one of the latest Ford motors, in which cylinders, upper half of the crankcase, and the gearbox are all cast in one

piece. The lower half of the crankcase and gearbox are similarly constituted of another simple pressed steel unit, while a second casting is used for the heads of the cylinders and the water connection.

Piston. The pistons of automobile motors have long been made of cast iron, with the piston pin held in bosses on the piston walls. For all ordinary service this construction, well carried out, serves every purpose, but with the development of very high-speed motors, with piston speeds twice and three times as high as past practice has sanctioned, there is a growing tendency to substitute steel for cast iron in this important reciprocating element.

Particularly in aviation motors has this been the case, the pistons of one well-known revolving motor, for example, being machined to the thinnest possible sections out of a high-grade alloy steel. In this motor the connecting rods are hinged to the head of the piston instead of to the walls, which thus can be made much thinner than otherwise would be necessary. This practice has been followed to a slight extent by some automobile manufacturers. There are now a few stock cars of established quality provided with pressed-steel pistons.

In cars, too, the movement toward smaller bores and higher efficiency has brought about the use of much lighter pistons, this being done by making them thinner and shorter. The latest development has been the use not only of aluminum pistons and die-forged aluminum alloy connecting rods, but also of aluminum cylinders having cast-iron sleeves driven in to form the actual cylinder surfaces.

Cast iron for piston rings, long used to the exclusion of everything else, is in slight degree yielding its pre-eminence for this purpose also. This is because it has been found, in aviation motors with steel cylinders, that bronze affords greater durability and smoother running against the steel cylinder wall, for which reason bronze rings—with steel or cast-iron springs, or "bull rings", behind them—have been found most advantageous. Multiple rings, three or more in a groove, are finding favor. Their thinness necessitates the use of steel.

Connecting Rods. Established practice in connecting-rod design is almost all in favor of the common H-section rod, usually with two bolts to attach the cap. In some cases four bolts are used, since with four bolts a flaw or crack in one is less likely to cause damage than is the case when only two are used. The old scheme of

hinging the cap at one side is now practically obsolete, having been discarded because of the fact that it made accurate adjustment of the bearing surfaces almost impossible.

Tubular rods, in place of the H-section, are giving good service in several of the long-stroke foreign motors, and it is difficult to see why this form is not superior to that in common use. The question of cost, however, is a consideration, since it is necessary to bore the hole through the inside of the rod, whereas a forged rod of H-section requires no machining except at the end.

The wonderful progress in welding, however, has made it possible to construct a tubular connecting rod at a very low expense, and, due

Fig. 7. Connecting Rod Machined Out of One Piece of Alloy Steel, with Four Cap Bolts

to its many advantages, this is finding much favor for small motors. The two ends are machined and a section of tubing welded to them.

One advantage of the tubular rod, in addition to its superiority for withstanding the compression load to which a rod is chiefly subject, is that it can be used as a pipe to convey oil from the big end to the piston-pin bearing.

In Fig. 7 is illustrated an example of a very light-weight, high-quality, aviation-motor connecting rod, machined out of a solid bar of alloy steel, and provided with four bolts in the cap.

Crankshafts. The greatest variations in automobile crankshaft design, aside from those permitted or made necessary by differences in the quality of material, are due to the conditions involved

in the different combinations of cylinders that can be utilized. Thus the number of crank throws, as well as their position, varies with the type of motor.

The duty of a crankshaft is of so severe a character, involving the practical equivalent of thousands upon thousands of heavy blows, that for any but very heavy, slow-running motors, the crankshaft should be made of nothing but the finest alloy steels obtainable.

Valve Mechanism. In the valves and valve mechanisms of modern gasoline engines there have been and are impending more interesting changes than seem in prospect in any other portion of the mechanism of the modern automobile. Particularly is this the case with reference to the present tendency to discard the poppet valve with its many objectionable features.

Even where there is no tendency toward the use of a sleeve-valve or slide-valve form of motor, much experimenting has been done with increasing the number and changing the position of the valves. As an example of the former, many of the cars in the last *Grand Prix* race, in France, had four valves for each cylinder, two inlets and two exhausts. As an example of the latter, the same race showed all but two makes of car with the valves in the head, either vertical or inclined, except in one case, in which they were horizontal.

Poppet Valves. Though the very first internal-combustion engines ever made were operated with slide valves, the poppet valve was introduced very early in the history of this art, and has reigned supreme in practically all types of gas and gasoline engines.

The chief advantage of the poppet valve is its capacity for continuing operative at excessively high temperatures, but since the cooling of engines has progressed to the status of high reliability this advantage is of less importance than formerly. And the disadvantages of poppet valves—the small openings that they afford, the noisy and hammering action they involve, their tendency to leak and in other ways give out, and the necessity for frequently regrinding them—are objections so serious that it is not to be wondered at that the prospect of their elimination is so widely welcomed.

About the only recent improvements that have been made in poppet valves are in the quality of material used in them—the best valves now being those with cast-iron and nickel heads, which offer a maximum resistance to warping from the heat to which they are

subjected, and with carbon-steel stems, which are superior in their wearing qualities. Much use has been made recently of tungsten as a material for valves. Steel containing this is even harder than nickel steel, and experiments have shown that it does not warp as much. In practice, the objection found to cast-iron heads was that the fastenings to the carbon-steel stem were not sufficiently strong to withstand the constant pulling and pushing to which a valve was subjected. As a result they separated, causing trouble.

In the operation of poppet valves, the cams become an important factor. These are the parts, which, in revolving, raise the valves

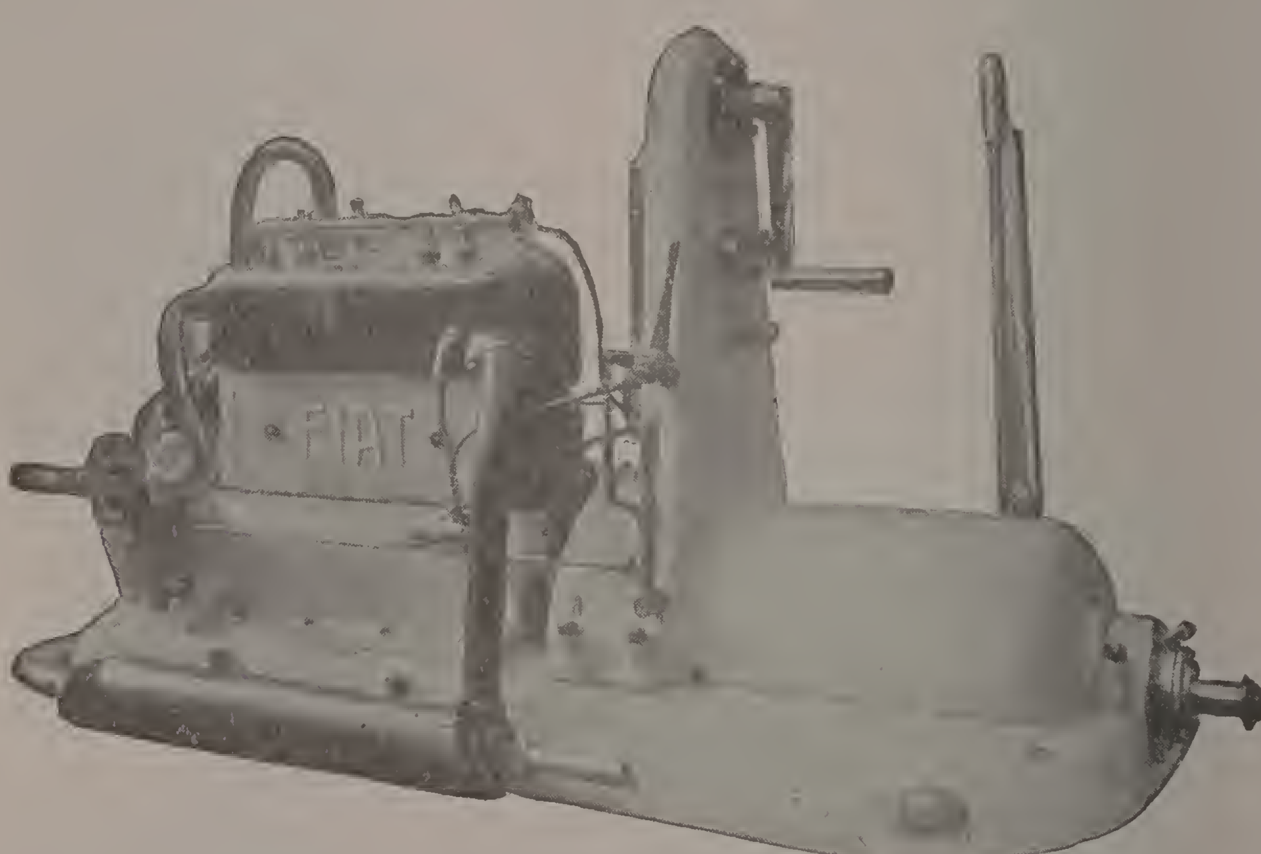


Fig. 8. Fiat Marine Motor with Encased Valve Action
This Photograph Protected by International Copyright

so that they open at the proper time. In addition, they are so shaped as to hold them open for just the right length of time, and allow them to close, through the medium of the valve spring pressure, at the proper point in the cycle. The importance of this can be seen, if we consider that opening the slightest fraction of a second too late will reduce the amount of the charge very much, and thus lessen the power developed by the motor.

Enclosures. The use of casings to enclose the valve stems, springs, and push rods, so as to keep these elements from exposure

to dirt, while at the same time silencing in large degree the noise they otherwise make, is also becoming usual.

An excellent example of this may be seen by referring back to Fig. 5, in which it will be noted that the whole side of the motor where the valve mechanism is located is covered with a long, removable plate, keeping in noise and lubricant, and keeping out dirt. Usually, however, on a six-cylinder motor the valve enclosure is made in two parts, one-half enclosing the mechanism of the valves in the

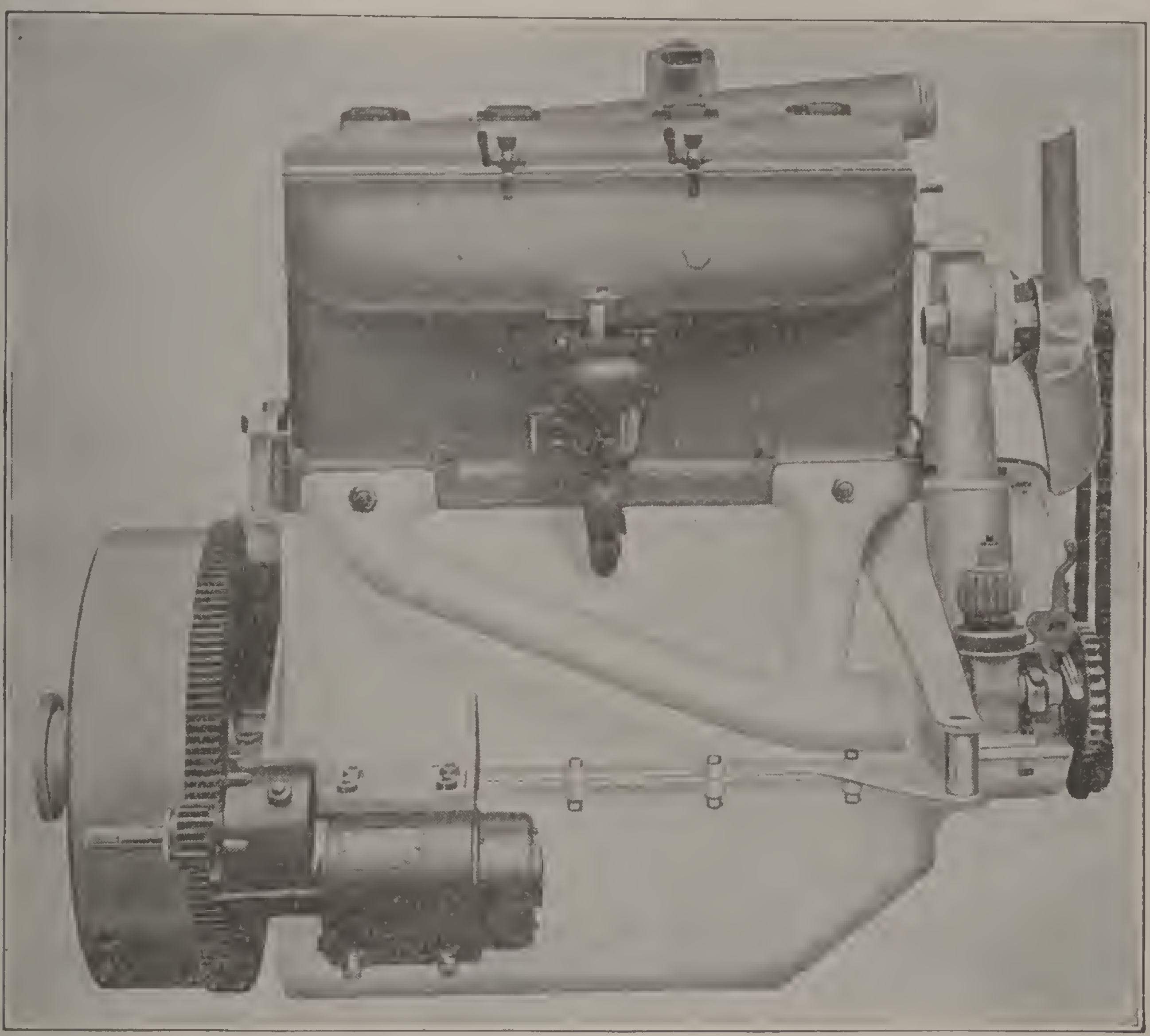


Fig. 9. Carbureter Side of Moline-Knight 50-Horsepower Motor
Courtesy of Moline Automobile Company, East Moline, Illinois

first three cylinders, the other, those in the last three. This is, of course, the preferred construction on those six-cylinder engines which have the cylinders cast in threes, instead of in a block, as the one referred to. On some motors where this construction has not found favor, the designers have followed the plan of enclosing the individual valve mechanisms. While more expensive, this method is equally as efficient. On the other hand, it adds to the parts, and the whole modern tendency has been to reduce the number of parts.

A characteristic example of present methods of casing in poppet valves is shown in Fig. 8, which is an example of a Fiat marine motor, with the valve stem pit in the side of the motor covered by a readily removable aluminum plate.

Sleeve Valves. This type of valve, while not at all new, has only within the past few years come into considerable prominence, chiefly as a result of the truly remarkable performances of the Knight motor, which is equipped with the most advanced examples of this type of valve.

Fig. 10. Single-Cylinder, Rotating-Valve Anzani Engine
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Contrary to past opinion, it has been conclusively demonstrated that sleeve valves do not in any perceptible degree increase the tendency of a motor to overheat, nor do they wear at any very measurable rate. They afford, moreover, in the best constructions, a much higher thermal and mechanical efficiency than it is possible to secure from the average poppet-valve motor, this improvement being due to the better-shaped combustion chamber that can be used, and the greater areas of valve opening, which facilitate the ingress and egress of the charges.

Another advantage in favor of the sleeve valve is that its timing is permanent and unchangeable, and does not alter materially with wear. Not the least of the merits of the sleeve valve is found in the fact that it lends itself to positive operation by eccentric mechanisms, which are in every way greatly superior to the non-positive cam mechanisms universally used to actuate poppet valves.

A very good example of this latest type of Knight motor is illustrated in Fig. 9, showing the intake side of the Moline-Knight four-cylinder motor.

Sliding Valves. Sliding valves of other than the sleeve type, embracing a considerable variety of piston valves and valves similar to those employed in steam engines, have not found as much favor with designers of automobile engines as have other types herein referred to.

One exception is the successful use of a "split-ring" valve, sliding up and down in the cylinder head just above the piston, which has found successful application in a few motors recently built by the Renault Company, of France.

Rotating Valves. A rotating valve of characteristic type is that employed in the single-cylinder engine illustrated in Fig. 10, which is an experimental motor designed by Anzani, famous as the designer of several European automobile motors, and of the aviation motor with which Bleriot effected the first flight across the English Channel.

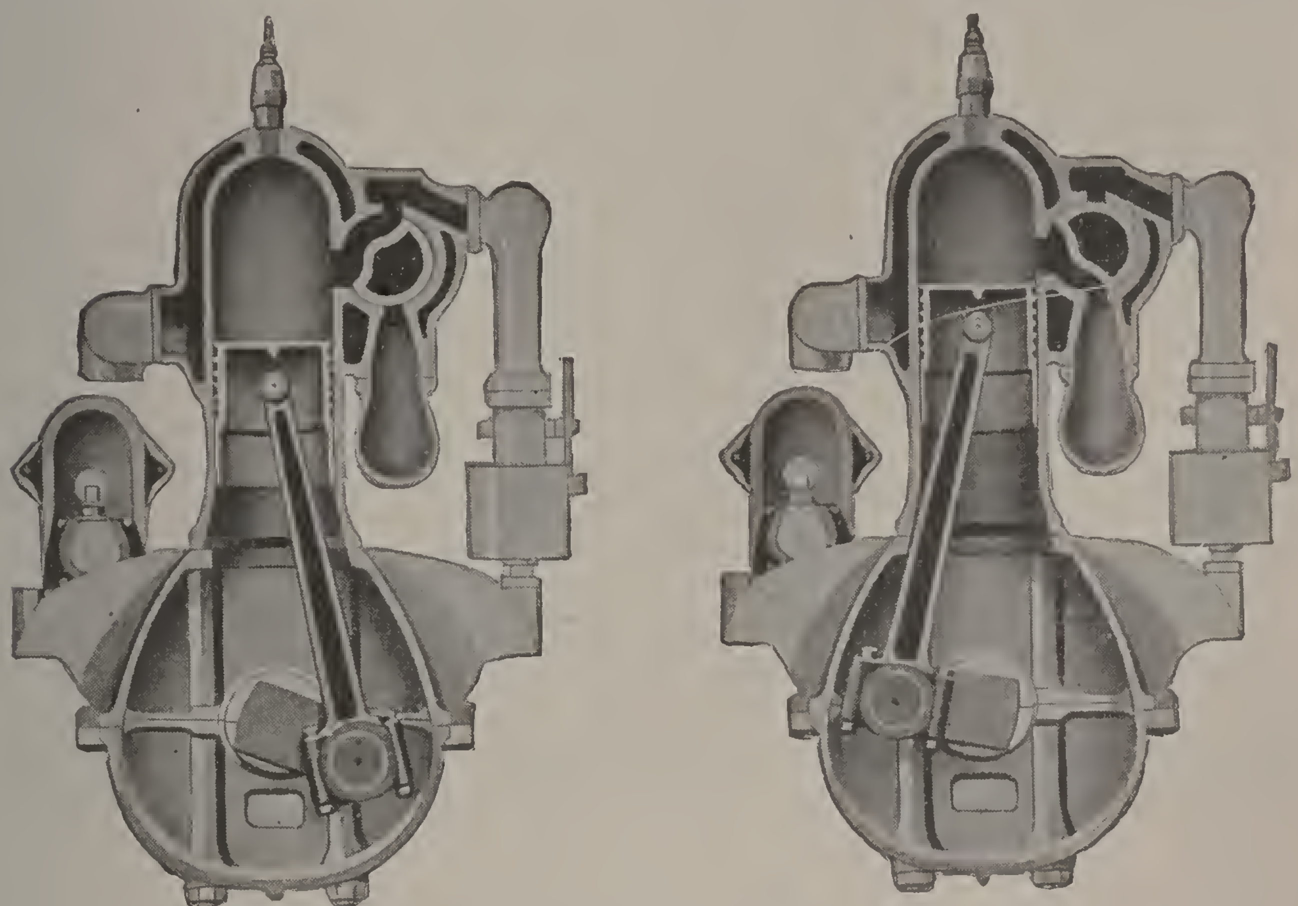

Fig. 11. Sections of Darracq Rotating Valve Motor, Showing Intake Position (left) and Exhaust Position (right)

This motor is provided with a plain rotating sleeve in the cylinder head, turned at a constant speed by skew gears.

Other rotating valves that have proved successful are the Darracq valve, illustrated in Figs. 11 and 12, and various rotating inlet valves used on the crankcases of two-cycle motors.

The Darracq rotating valve is a particularly clever example of sound designing, and exhaustive tests have proved it thoroughly successful and reliable.

Much of its merit undoubtedly inheres in the fact that the port through which it communicates with the cylinder is closed by the piston at the top of the stroke, so that at the moment of explosion

the valve is shielded from the highest temperatures that occur within the cylinder.

An American motor of somewhat similar general form has a pair of these valves on opposite sides of the cylinder head, driven, however, by silent chains. The only difference in the action from that described and illustrated is the simplification and reduction of sizes made possible by having the exhaust on one side and the inlet on the other.

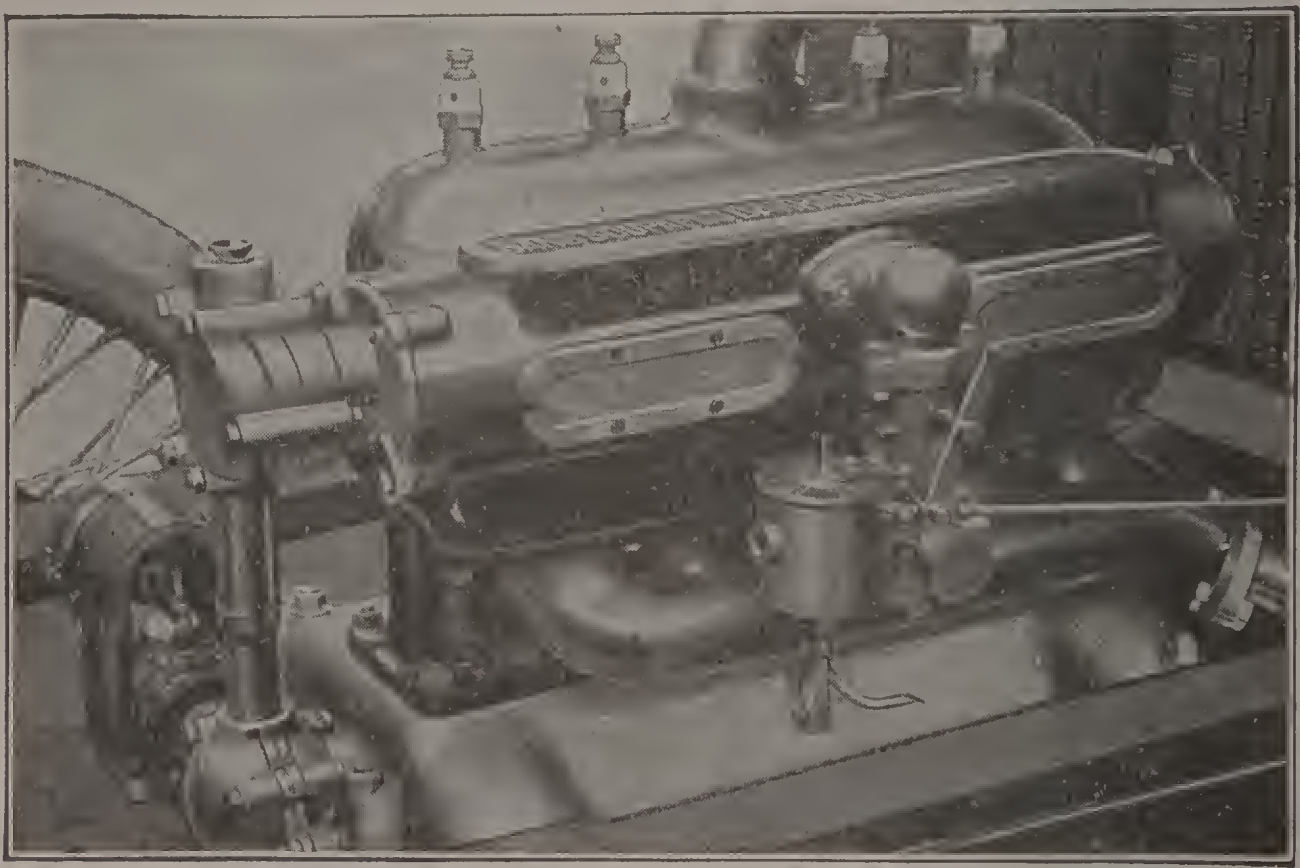

Fig. 12. Complete Darracq Rotating Valve Motor
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Half-Time Shafts. For the actuation of the valve mechanism of any four-cycle motor, it is necessary to have a shaft (or in the case of rotary valves, to run the valve itself as a shaft), turning at one-half the speed of the crankshaft through a two-to-one gear ratio.

Ordinarily the half-time shaft is the camshaft, but in motors of the Knight type it is, of course, an eccentric shaft. Camshafts particularly call for good workmanship and high-grade materials, as well as sound design, since the constant pounding of the valve stems or push rods on the cams is a prolific source of trouble, if anything but the soundest of sound construction be employed.

The most important recent innovation in this detail of automobile mechanism is the driving of half-time shafts by silent chains

in place of the long-used gearing, of spur and helical type. By this improvement the noise of the gears is eliminated.

A typical silent chain running over a pair of gears may be seen in Fig. 13. These, however, present very broad-faced gears, while the usual timing gears would have a narrow face. In the use and action of the silent chain, this makes little or no difference. In the Cadillac motor, shown in Fig. 2, a pair of these is used, one driving the camshaft from the crankshaft while the other drives the auxiliary shaft from the camshaft. In the American form of Knight sliding-sleeve-valve motors shown in Fig. 9, a pair of silent chains is used for the eccentric shaft on one side and the electric generator on the other. These are driven from a pair of sprockets set side by side on an extension of the crankshaft.

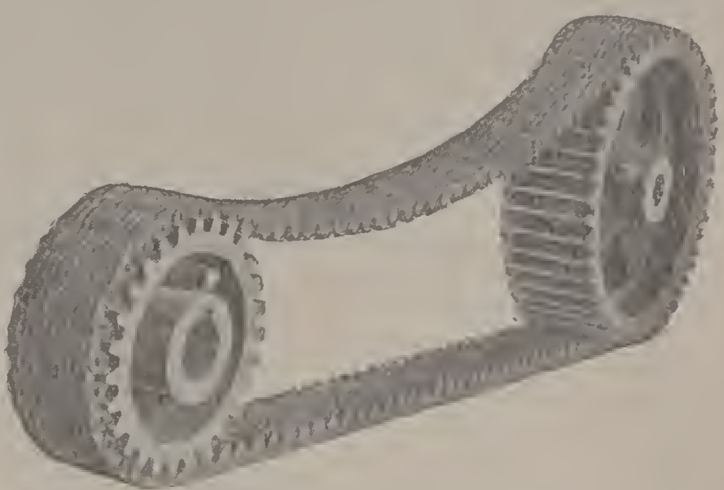

Fig. 13. Silent Chain and Sprockets

A point that should be brought out in connection with silent-chain camshaft driving is that the use of the chain allows the shafts to be placed anywhere desired, and thus, to a certain extent, frees the designer from the former restriction of a two-to-one reduction ratio in the gears, which rather fixed the size, and consequently the position of the gears. This had an influence also upon cylinder design, as the center of the camshaft fixed the center of all the valves—that is their distance from the center line of the motor.

VALVE GEARS

Probably the most important thing about a four-cycle gasoline engine is the valve, or more correctly, are the valves, for the usual number is two per cylinder. The opening and closing of these control the functions of the engine, for if the valve does not open and allow a charge of gas to enter, how can the piston compress, and the ignition system fire, a charge? Similarly, if the exhaust valve is not opened and the burned gases allowed to escape, they will mingle with and dilute the fresh, incoming charge, possibly to the extent of making the latter into a non-combustible gas.

CAMS

Friction. Granting the necessity for proper means to regulate the inflow and outgo of the charge and consequent products of combustion, as exemplified by the valves, the next most important part is the one which controls the movement of the valve, and is, therefore, essential to the success of the latter. This is what is known as a cam and in the usual case amounts to an extension of or projection from the so-called camshaft. Inasmuch as the valve func-

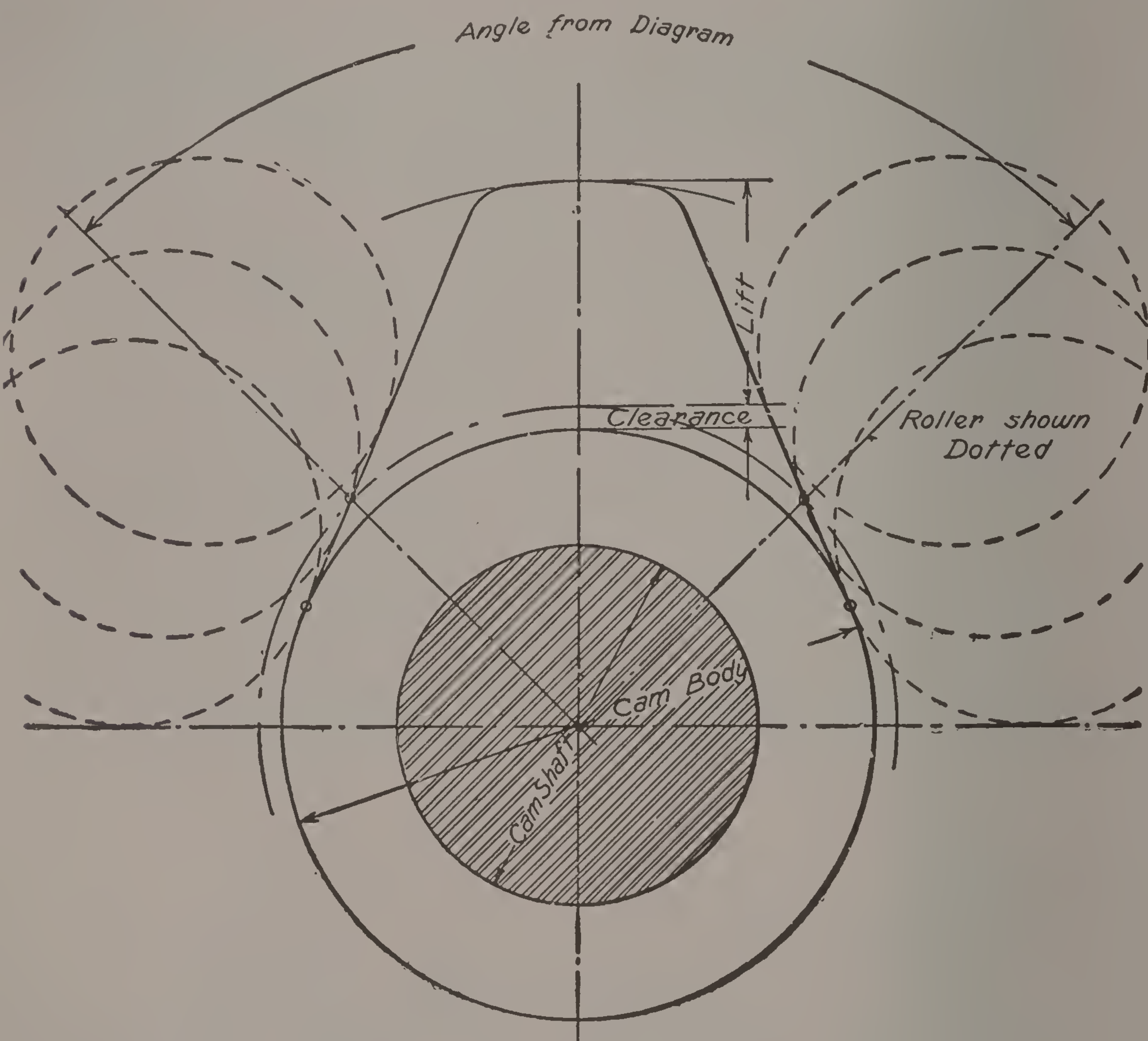

Fig. 14. Method of Laying Out Cams

tions only come into play upon every other stroke of the crankshaft, this camshaft is gear-driven from the crankshaft, so as to rotate at half the speed of the latter. This is very simply effected by having the cam gear twice as large as the crankshaft gear, that is, with twice as many teeth. As the same valve is never used for both the inlet and the exhaust, so the cams are seldom made to do more than the one thing, namely, operate one of the valves. From this has

grown the custom of referring to them according to the function of the valve which they operate—inlet cam, exhaust cam, etc.

Cam Design. In order to lay out a set of cams, not only must the cycle be fixed, but the clearance as well. Fig. 14 shows the way to go about this; the size of the shaft is simply determined, and if other means fail, the empirical formula may be used:

$$\text{Camshaft diameter} = .625D - \tfrac{1}{8}''$$

in which D is the clear diameter of the valve opening in inches.

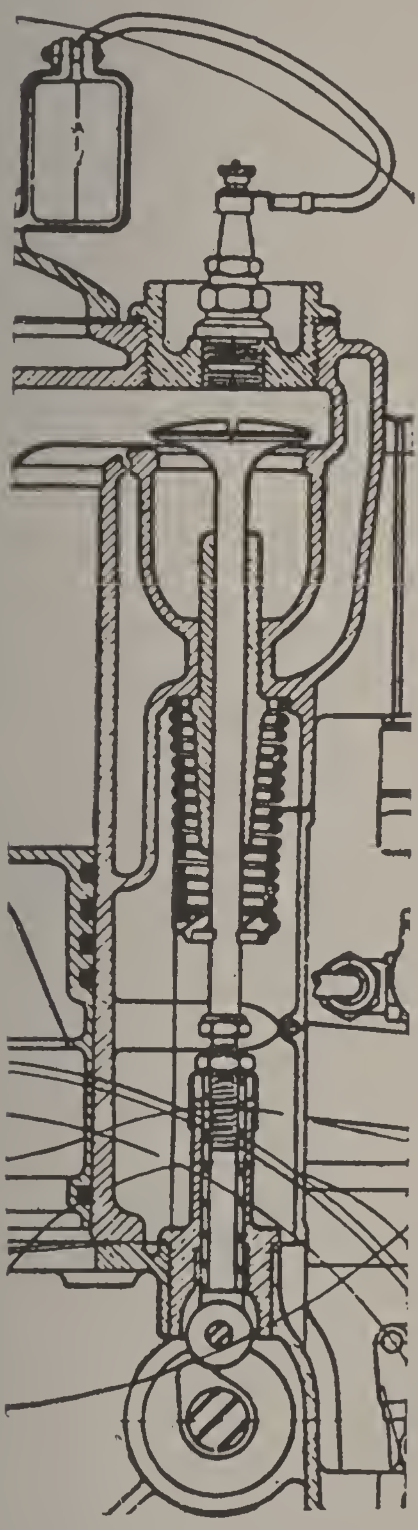

Fig. 15. Complete Valve Motion with Roller Push Rod
Courtesy of Locomobile Company of America, Bridgeport, Connecticut

Having the camshaft diameter fixed, lay it out and about it circumscribe the cam thickness. This may be from one-eighth of an inch, upon very small, light-weight engines, to three-eighths inch on larger and heavier motors. Around this, in turn, describe another circle, distant from the cam surface a distance equal to the clearance. A fourth circle representing the height is shown only partly complete.

From the cycle previously determined upon, the total angle of inlet valve opening, for instance, is found by simple addition and subtraction; thus, if the inlet is to open 10 degrees past the upper center and close 20 degrees past the lower center, this makes the valve remain open a total of 190 degrees upon the crankshaft. As the camshaft turns but half as fast and, therefore, but half as far in the same length of time, for the cam this angle will be halved, or 95 degrees. Proceed to lay out half of this, or $47\frac{1}{2}$ degrees, on each side of the vertical center line. A line forming this angle with the center line will intersect the line representing the clearance in a point. Through this point draw a line which will be tangent to the circle representing the surface of the cam, and prolong it upward to meet the

upper circle. Drawing in a round corner completes the cam layout. By sketching in the cam roller the progression is shown. Figs. 15 and 16 illustrate the complete valve action very well, the former, that of the Locomobile Company of America, Bridgeport, Connecticut, showing the form in which the cam works against a roller in the bottom of the push rod, this working upward in the push rod guide with a dirt excluding arrangement at the top. The top of the push rod bears against the bottom of the valve stem with an adjustable hardened screw forming the contact. The valve is held down on its seat in the cylinder by means of a strong spring, which the upward movement of the push rod opposes. The valve is guided in and has its bearing in the valve guide, made long to give large bearing surface. As the Locomobile motor is of the T-head type the exhaust and inlet valves are on opposite sides of the cylinders and are operated by separate camshafts. The valve mechanism is completely enclosed.

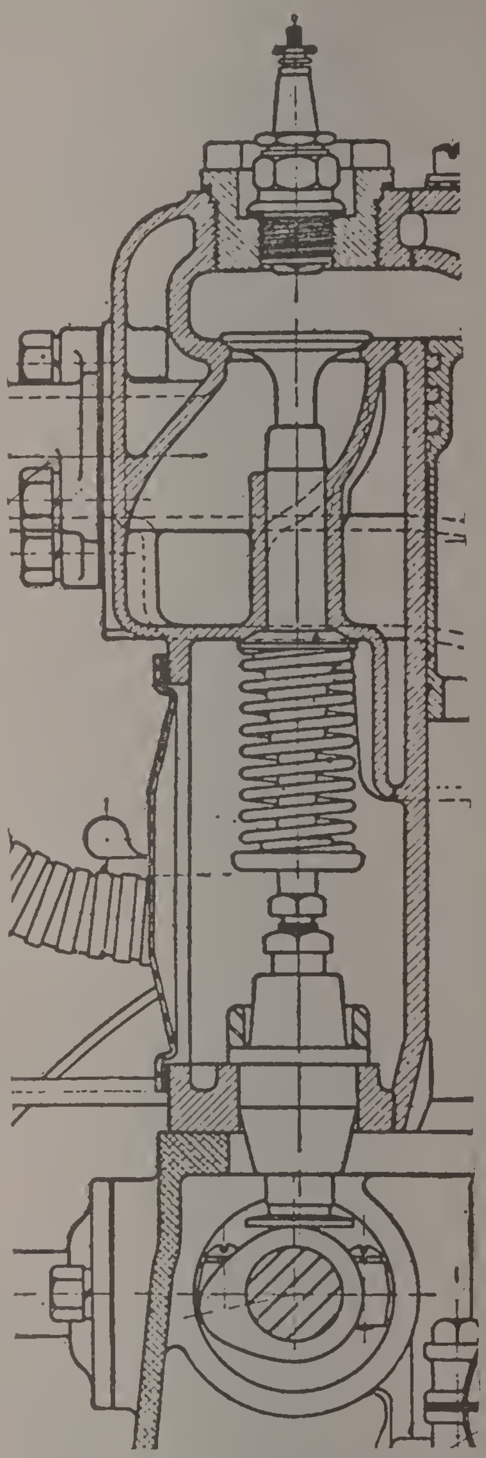

Fig. 16. Complete Valve Motion without Roller in Push Rod
Courtesy of Haynes Automobile Company, Kokomo, Indiana

The second figure shows the valve action used on Haynes cars, made by the Haynes Automobile Company, Kokomo, Indiana. The difference is in the elimination of the roller at the bottom of the push rod, which forms the point of contact with the cam. In this form, a flat hardened surface makes the push rod more simple and reduces the number of parts. It has been said against this form that the cam scrapes across the push rod face and thus wears it, but in actual use it has been found that the push rod rotates and in this way the wear is distributed over the whole flat face, which in this construction can be made much larger than can the face of the roller. The push rods are of the "mushroom" type and are

made of nickel steel. The push rod adjustments are completely enclosed but may be readily reached without disturbing any other unit. They may be removed and replaced without removing the valve springs or valves.

Neither of these systems is in decided favor, designers being about equally divided between them.

The construction and operation of the cam mechanism is the same whether used in connection with an exhaust or an inlet valve, as the same line of reasoning and the same method of procedure

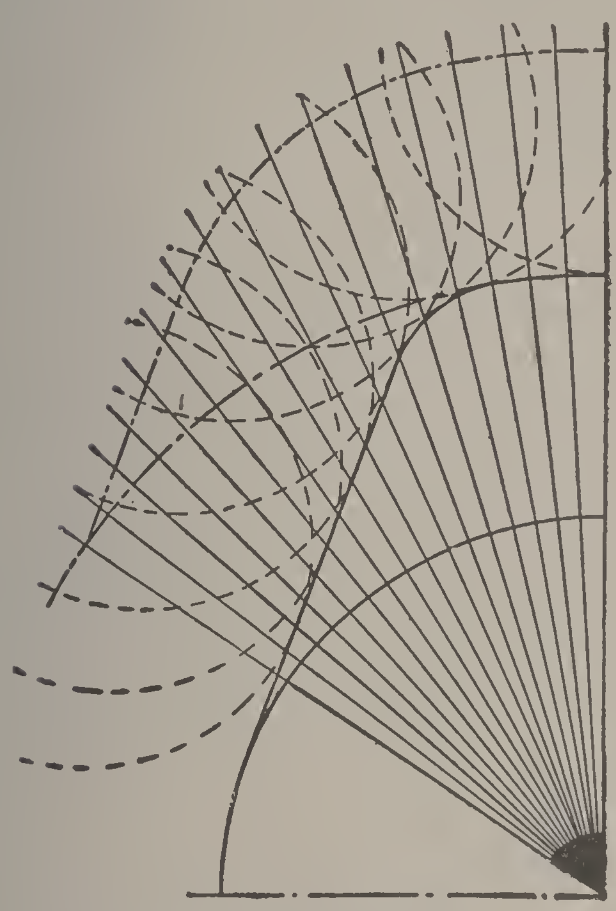

Fig. 17. Straight-Sided or Ordinary Cam

Fig. 18. Lay-Out for Uniform Acceleration Cam

in both cases would lead to the same results. It will be noticed in Figs. 14 and 17 that the straight sided cam has been chosen to illustrate the elements of design.

It has many times been tried and still more often urged that the straight surface of the side of the cam is not conducive to the best results, because of the fact that when the first straight portion of the cam surface strikes the cam roller it does so with so much force that it tends to wear the latter in that direction. As for the receding face, it has been urged that the ordinary closing of the valve is too slow, and that the straight surface, as shown in Fig. 17, can be altered so as to allow of speeding up the downward move-

ment of the valve. This idea works out into a curve, Fig. 18, the back of the surface being hollowed out so that as soon as the cam roller passes the center it drops vertically, due to the tension of the spring. This method has been tried, but without success.

What Good Modern Practice Shows. A more modern way, which is fast becoming universal, is to use straight sides for the cams and take advantage of rapid closing in another way, the benefits of which more than offset the benefits of the old way, while having no corresponding disadvantages. In the ordinary automobile engine running at 1000 revolutions per minute, the gases are traveling into the cylinder at the rate of 5000 to 6000 feet per minute, and traveling out at from 7000 to 10,000 feet per minute. At this tremendous speed, the gas inertia is very high, and experiments go to show that the gases by means of this inertia will continue to force their way into the cylinder even against the return motion of the piston. So it is now common practice to hold the inlet valve open about 30 degrees on the upstroke of the piston, which results in a much larger piston charge. The same practice is carried out with the exhaust, but as the pressure is higher, so large an angle is not necessary. These actions take place on the *back*—flat side—of the cam surface, and have given to the high-spced automobile engine a larger charge and a more complete scavenging effect, resulting in more power and speed from the same sized cylinder.

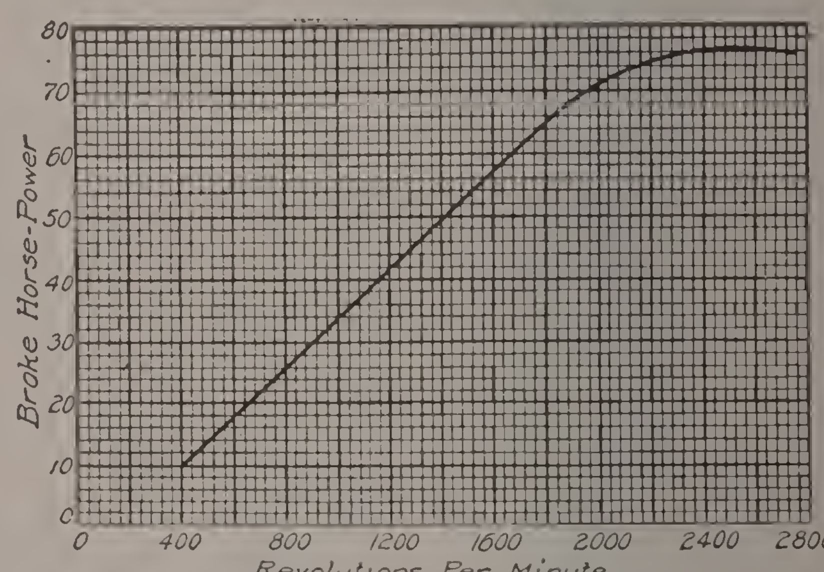

Fig. 19. Power Curve of an American Engine with Superior Cams and Balancing

As proof of this statement, the power curve of an engine of but $3\frac{1}{2}$-inch diameter of cylinder is shown in Fig. 19. This size of six-cylinder engine would be rated by any formula at about 29 horsepower at the maximum speed, and a commercially obtainable type in this size would doubtless be guaranteed to deliver between 20 and 25 horsepower. This engine, not built for racing purposes,

displays a power curve which continuously rises, a speed at which it would turn downward not having been obtainable in the tests. This curve shows also that the maximum power obtained was over 30, which is nearly three times the power of the ordinary engine of this same size. This result is ascribable to superior valves and superior attention to the valve angles as governed by the cams.

When it was stated that but two valves per cylinder were ordinarily used, with one cam for each, the majority case was spoken of. But, as it is a fact that there are other cases which differ from this, it would not be fair to close the subject without mentioning them. Thus, the most prominent advocate of air cooling in this country and the world, the H. H. Franklin Manufacturing Company, used three valves, and consequently three cams, per cylinder. These three were: the ordinary *inlet;* the usual *exhaust;* and the additional *auxiliary exhaust.* By re-designing later, this complication was avoided and the third valve eliminated.

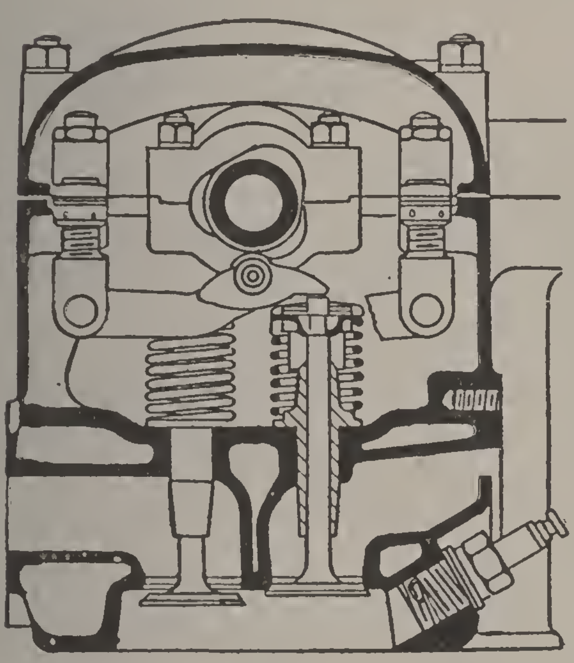

Fig. 20. Overhead Valve Motion with Followers Working Directly on Valve Stems and Having no Push Rods
Courtesy of Chalmers Motor Company, Detroit, Michigan

One Cam per Two Valves Influences the Shape. A case in which the cam does differ is that of the use of two overhead valves operated by a single camshaft, Fig. 20. This practice originated with the F. I. A. T. Company, which brought it out for racing use only, where it was particularly useful in that it halved the weight of the camshaft, as well as saved much weight in push rods, etc. Later, this was taken up by other firms for regular use, although the company which first brought it out has never done so. In our own country, the device was adopted by the Pope Toledo Company, the Stoddard-Dayton, De Luxe, and others. The work of opening the extra valve is done by a spring, i.e., a depression in the back of the cam allows a strong spring to pull the push rod down, by which process the valve stem is depressed and the valve opened.

The V-type of motor has made considerable difference in valve motions, for one thing bringing into use valves set at an angle with

the vertical, a practice previously considered very bad because the weight of the valve adds to the tendency to wear the valve and seat on the low side. In the form shown in Fig. 21, the eight-cylinder motor used in the Briscoe 38, made by the Briscoe Motor Company, Jackson, Michigan, there are no unusual features. The single camshaft with 16 cams is centrally placed in the middle of the V and operates the push rods, inclined outward, parallel to their respective groups of cylinders. A rocker arm, or follower, is used at the cylinder heads to

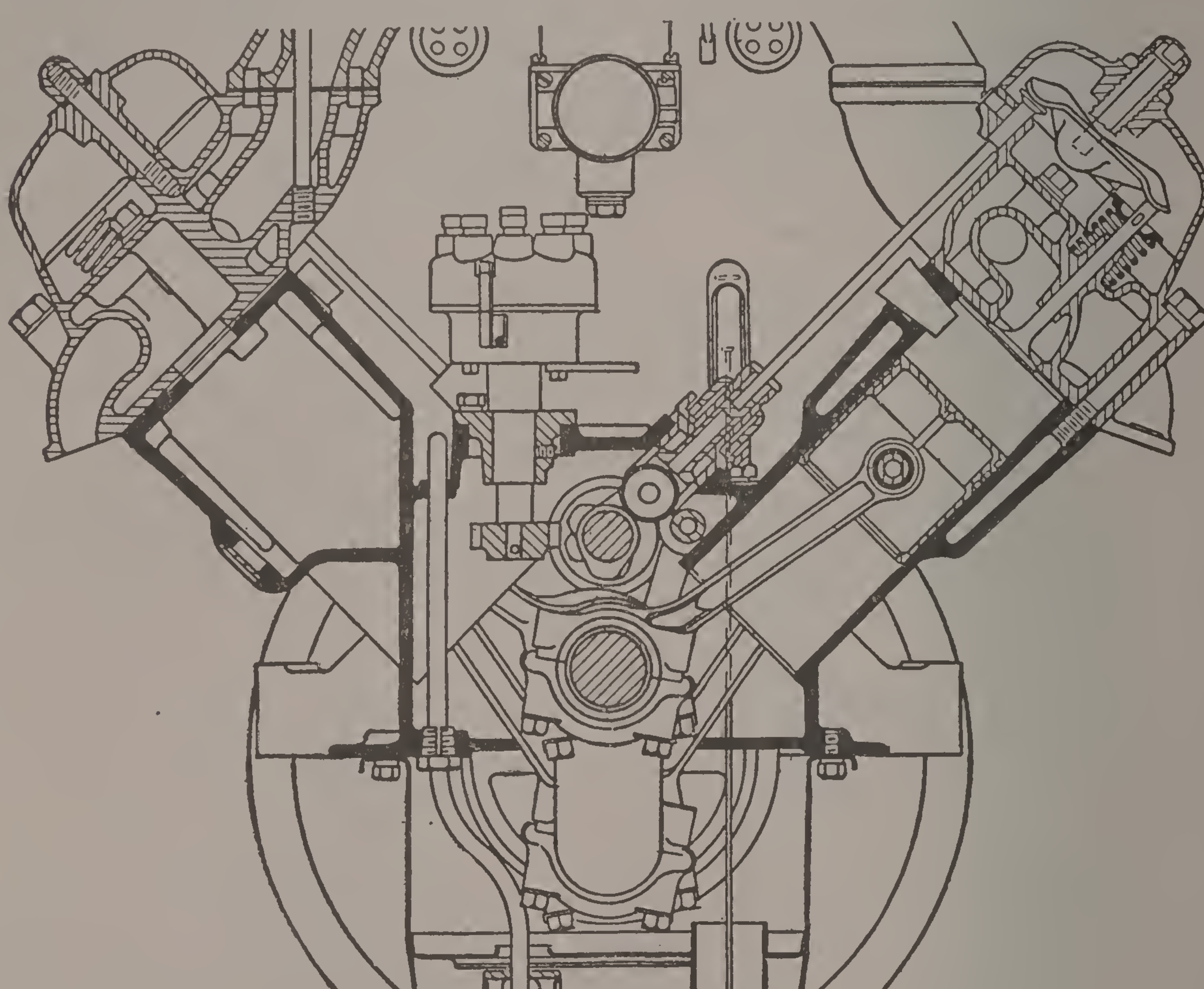

Fig. 21. Section through Briscoe Eight, Showing Camshaft Arrangement

transfer this up-and-down motion to the valves which are set in the center of the cylinder heads and are thus parallel to the push rods.

In the majority of V-type motors, both eights and twelves, the valves are in side pockets, the cylinders being of the L-type, and thus there is no radical innovation except the inclined push rods and valve systems. In a few of these motors, however, a follower is used between the cams and the push rods because of other structural reasons.

When any kind of a cam follower is used differing from the usual direct-lift push rod, this may or may not affect the shape of the cam. Usually it does not, so that the shape

does not have to be taken into account. Ordinarily these followers are used to prevent side thrust on the push-rod guide, the follower itself taking all the thrust and being so designed as to be readily removable or adjustable, to take care of this. In cases where this does not obtain, the object usually sought is the removal of noise. The two objects may be combined as in the case shown in Fig. 22. This represents an enlarged view of the cam mechanism of the famous one-cylinder French car, Peugeot. It will be clear that the action is that of one cam operating both the exhaust and the inlet valves through the medium of a pair of levers, upon which the cam works alternately.

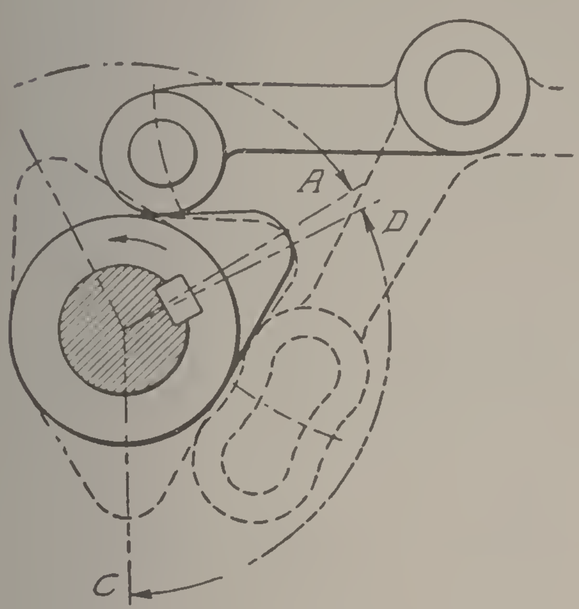

Fig. 22. Cam Mechanism of Peugeot Single-Cylinder Engine

Difficulties in Making Cams. There was a time when the production of a good, accurate camshaft was a big job in any machine shop, well-equipped or otherwise, and represented the expenditure of much money in jigs, tools, and fixtures. Now, however, the machine-tool builder has come to the rescue of the automobile manufacturer, and special tools have made the work easy. So it was with the production of the shaft with integral cams; this used to be a big undertaking but, today, special machinery has made it an easy matter. The illustrations, Figs. 23 and 24, show some of the product of a cam milling machine. This is now the favored way of putting out engines, for the integral cams and shaft have the advantage of much lower first cost and, with proper hardening, will last fully as long as those made by cutting the cams separately and assembling them in their proper position on the shaft.

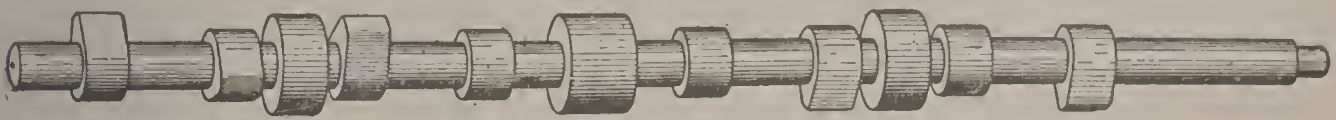
Fig. 23. Cams Integral with Shaft—Milling Machine Job

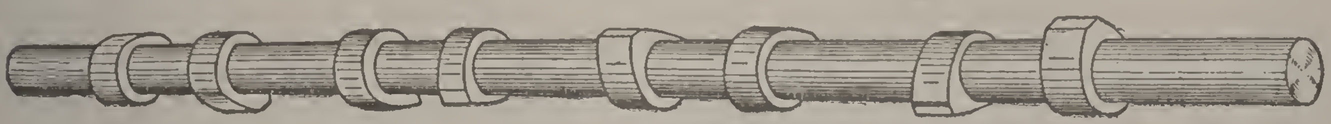
Fig. 24. Another Camshaft with Integral Cams

Grinding Increases Accuracy. An even later improvement in the way of a machine for producing cams on an integral shaft is the grinding machine which has been developed for this purpose. This works to what is called a master camshaft—that is, a larger-sized shaft which has been very accurately finished. This master shaft is placed in the grinding machine, the construction of which is such that the grinding wheel follows the contour of the very accurate master shaft and produces a duplicate of it, only reduced in size, a reducing motion being used between master shaft and grinder-wheel shaft.

The result of this arrangement is a machine which is almost human in its action, for it moves outward for the high points on the cams and inward for the low spots on the shaft. Moreover, it has this further advantage that all shafts turned out are absolutely alike and thus accurately interchangeable. It allows also of another arrangement of the work, the drop-forging of the shafts within a few thousandths of an inch of size; the surface of skin is easily ground off in one operation, then the hardening is done, and the final grinding to size is quickly accomplished. In this way, the shafts may be produced more cheaply than was formerly the case, and have in addition the merits brought out above, namely, greater accuracy, superior interchangeability, and quicker production.

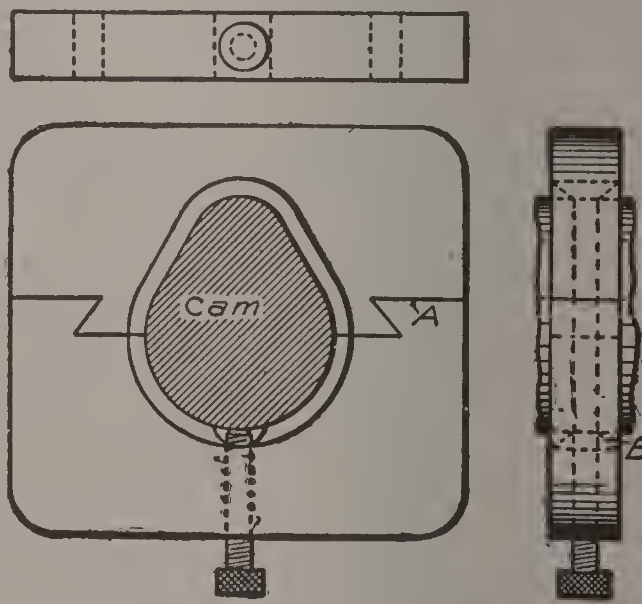

Fig. 25. English Cam Gage

The same process is applicable to, and is used for, other parts of the modern motorcar; thus crankshafts are ground, pump and magneto shafts are finished by grinding, and many other applications of this process are utilized. The process can be extended indefinitely, the only drawback being that a master shaft is very expensive.

Old Way Required More Accurate Inspection. With the old method of making the cams and shaft separate, the amount of inspection work was very great and represented a large total expense in the cost of the car. Thus, it was necessary to prove up every cam

separately, as well as every shaft, and, later, the cams and shaft assembled. One of the forms of gages used for inspecting cams is shown in Fig. 25. It is in two pieces, dovetailed together. This allows of the testing of many shapes of cam with but one base piece and a number of upper or profile pieces equal to the number of different cams to be tested. To test, the cam is slipped into the opening, and if small, the set screw forces it up into the formed part of the gage, showing its deficiencies; while if large, it will not enter the form.

REPAIRING VALVES AND VALVE PARTS

The interest of the repair man in all these valve-motion parts is quite different from that of the designer, for he cares not so much how they are made as how they are taken out, repaired, and put back, when accident or wear make this work necessary. To the repair man suitable tools for doing this kind of work are also of interest, particularly those for reaching inaccessible parts or for doing things which without the tools could not be done.

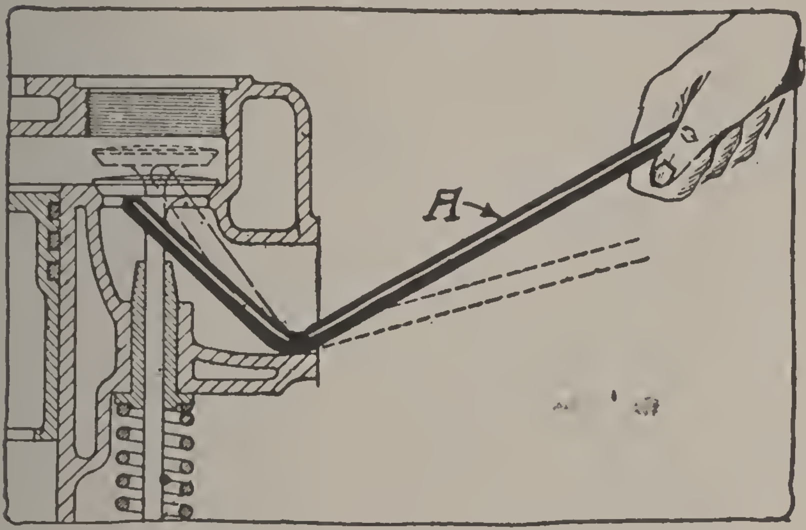

Fig. 26. Bent Tool Which Facilitates Removal of Stuck Valves

Curing a Noisy Tappet. Valve springs and the valves themselves, either at the seat end or at the tappet end, give the most trouble. For example, when the clearance between the end of the tappet and the end of the valve (usually from $\frac{3}{1000}$ to $\frac{8}{1000}$ inch) is too great, a metallic click results. Often this noise from the tappet is mistaken for a motor knock; but the skilled repair man has little trouble in finding and remedying it, for even if he cannot measure in thousandths of an inch, he knows, for instance, that the ordinary cigarette paper is about $\frac{3}{1000}$ inch in thickness and from this he can estimate $\frac{3}{1000}$, $\frac{6}{1000}$, or $\frac{9}{1000}$ inch. Ordinary thin wrapping paper is well known to be about $\frac{5}{1000}$ inch; with this alone, or in combination with cigarette papers he can obtain $\frac{5}{1000}$, $\frac{8}{1000}$, $\frac{10}{1000}$, and $\frac{11}{1000}$ inch, practically all the variation he is likely to need.

Removing Valve. Getting the valve out frequently gives much trouble, the valve often being found frozen to its seat or with the stem gummed in its guide. A tool to meet this difficulty is a plain bar or round iron about $\frac{1}{4}$ inch in diameter, Fig. 26, with one end, for a distance of perhaps 2 or $2\frac{1}{2}$ inches, bent up at an angle of about 120 degrees. To use the tool, insert the short bent end in the exhaust or the inlet opening, according to which valve is stuck, until the end touches the under side of the valve head, then lower the outer end until the bottom of the bent part or point at which the bend occurs rests against solid metal. The outer end can now be pressed down, and with the inner end acting as a lever the valve can be pressed off its seat and out very quickly.

To make this clearer, the rod, Fig. 26, is indicated at *A*, while the dotted line shows how it is pressed down and the valve forced out. The garage man can elaborate upon the tool when making it for himself by using square stock and having the inner end forked so as to bear on each side of the valve. The form pointed out above is the simplest, cheapest, and easiest to make.

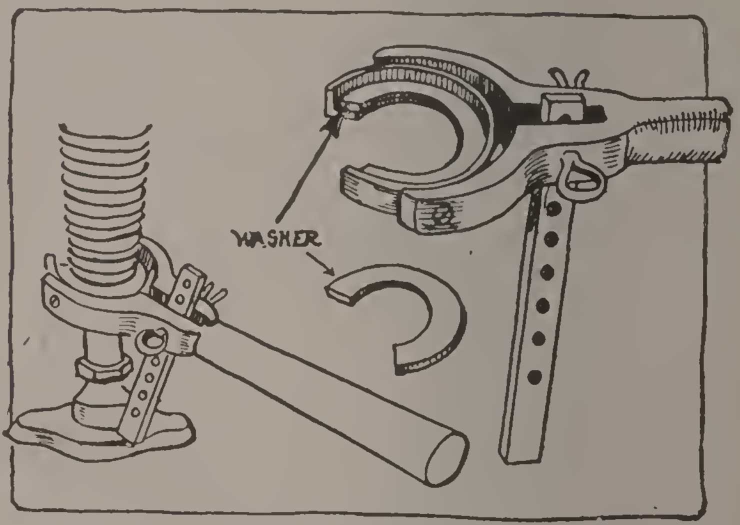

Fig. 27. Easily Made Tool for Removing Valve Spring

Removing Valve Spring. Taking out the valve spring is frequently difficult for various reasons; perhaps the springs are very stiff, or they may have rusted to the valve cups at the bottom, or the design may not allow room enough to work, etc. At any rate the removal is difficult, and a tool which will help in this and which is simple and cheap, is in demand. Many motor cylinders are cast with a slight projection or shelf opposite the valve spring positions, so that one only needs a tool that will encircle the lower end of the valve spring and rest upon this ledge, and give an outer leverage.

In working on cylinders that do not have this cast projection, a tool like that shown in Fig. 27 is useful. It consists of a yoke for encircling the lower end of valve spring and cup, with a long outer arm for prying, and a slot into which is set a drilled bar. This bar

is placed in various positions according to the kind of motor which is being worked on; when removing a valve-spring key, the lower end of the bar rests upon the crankcase upper surface, or upon the push-rod upper surface if that is extended. After slipping the grooved yoke under the spring cup, a simple pressure on the outer end raises the valve so the key can be withdrawn. Then the removal of the tool allows the valve spring to drop down, and the valve is free.

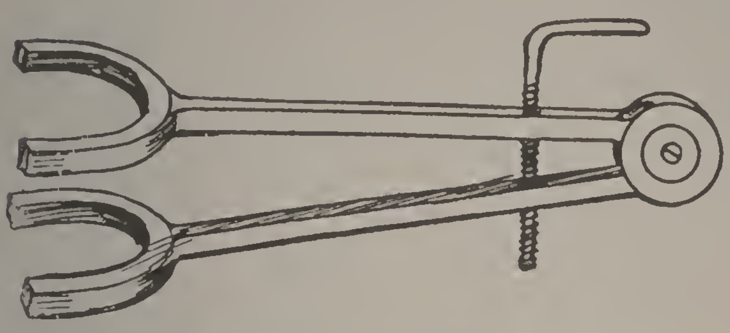

Fig. 28. Type of Valve-Spring Tool Which Leaves the Hands Free

The valve spring may be removed in two other ways by the use of the two tools shown in Figs. 28 and 29. In the former, the idea is to compress the spring only, no other part being touched. This tool once set, will continue to hold the spring compressed, leaving the hands free—a decided advantage over the tool shown in Fig. 27. This device consists, as the illustration shows, of a pair of arms with forked inner ends and outer ends joined by a pin. A bent handled screw draws the ends together or separates them according to which way it is turned.

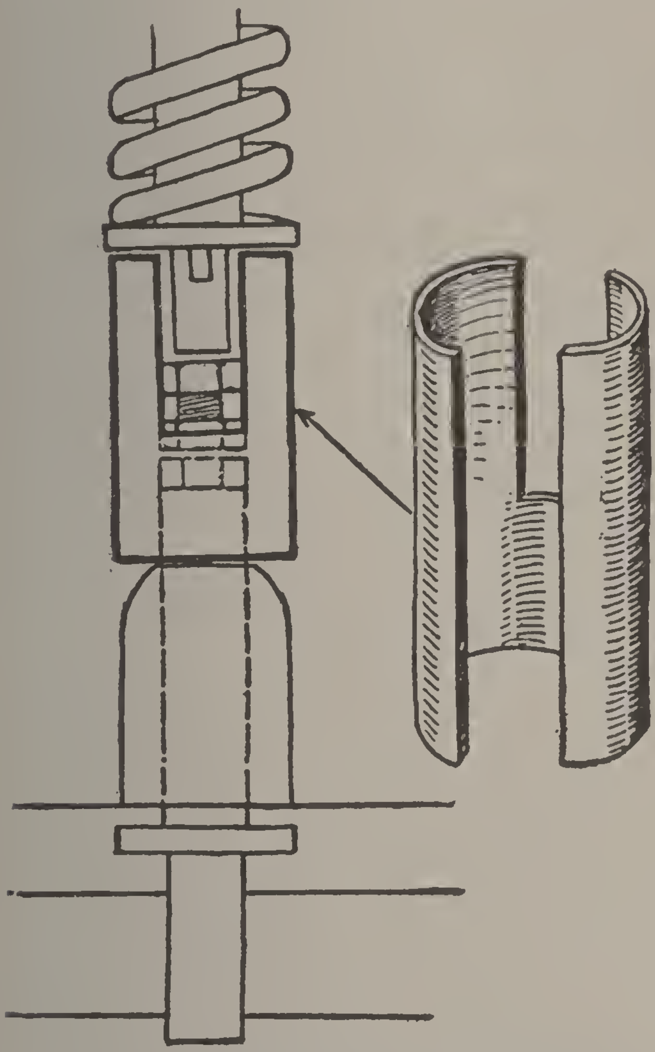

Fig. 29. A Substitute for a Valve Spring Remover Which Pushes Spring Away as Motor is Turned

The simplest tool of all is the one shown in Fig. 29, simply a formed piece of stiff sheet metal which is set into place when the valve is open. Then when the valve is closed by turning the motor, the sheet metal piece holds the spring up in its compressed position.

Holding Valve Springs Compressed. Many times there is a need for holding the spring in its compressed form, as, for instance,

when the valve is removed with the positive certainty that it will be replaced within four or five minutes. In such a case a clamp which will hold it in compression is very useful for it saves both time and work. These may be made to the form shown in Fig. 30 in a few minutes' time, for they consist simply of a pair of sheet metal strips with the ends bent over to form a very wide U shape. A pair of these is made for each separate make of valve spring, because of the varying lengths, but as they are so easily and quickly made this is no disadvantage.

In many shops, after getting in the habit of making these clamps, the workmen take this way of replacing the spring in preference to all others. After removal of the valve, the spring may be compressed in a vise and a pair of the clamps put on. Then when the valve is ready to go back in, the spring is as easy to handle as any other part. This is especially true when replacing the spring retainer and its lock.

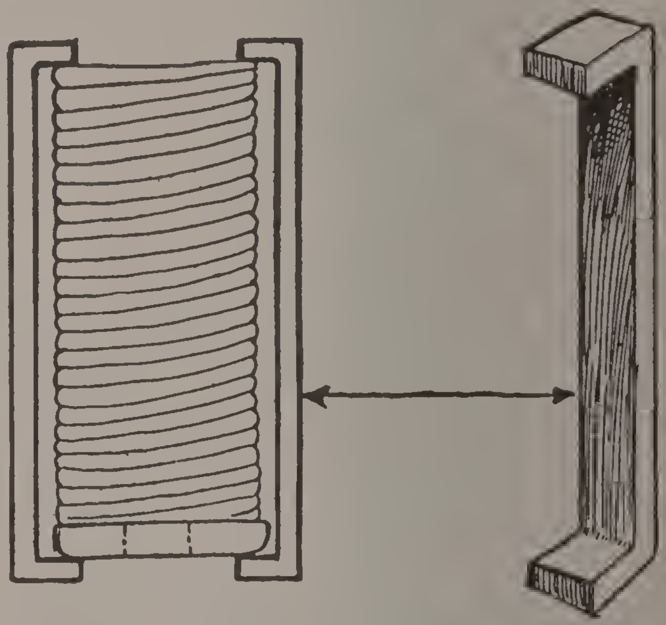

Fig. 30. Spring Clamp, Which Is Easily Made and Saves Much Work and Trouble

Stretching and Tempering Valve Springs. Many times when valve springs become weakened, they can be stretched to their former length, so that their original strength is restored. This can be done by removing them and stretching each individual coil, taking care to do it as evenly as possible. When well stretched, it is advisable to leave the coils that way for several days. This method will not, of course, restore the strength permanently; it is at best a makeshift, for in the course of a few thousand miles the springs will be as bad as before.

Sometimes weakened valve springs may be renewed by retempering, on the theory that the original temper was not good or they would not have broken down in use. The tempering is done by heating to a blood-red color and quenching in whale oil. If this is not successful, new springs are advised.

Adjusting Tension of Valves. Unless all the valves on a motor agree, it will run irregularly—that is, all the exhausts must be of

the same tension, and all the inlets must agree among themselves, though not necessarily with the exhausts. Many times irregular running of this kind, called "galloping", is more difficult to trace and remove than missing or other more serious troubles, and it is fully as annoying to the owner as missing would be.

To be certain of finding this trouble, the repair man should have a means of testing the strength of springs, a simple device being shown in Fig. 31. As will be seen, this consists of sheet-metal strips and connecting rods of light stock, with a hook at the top for a spring balance and a connection at the bottom to a pivoted hand lever for compressing the spring. By means of the center rod at *R* and the thumb screw at the bottom, the exact pressure required to compress the spring to a certain size may be determined. Thus, suppose the spring should compress from 4 inches to 3½ inches under 50 pounds. By compressing it in the center portion of the device, so that the distance between the two adjacent strips of metal indicated by *S* is just 3½ inches, the spring balance should show just 50 pounds. If it shows any less, the spring is too weak and should be discarded; if it shows any more, it is stronger than normal—which is desirable if all the other springs on the same engine are stronger also.

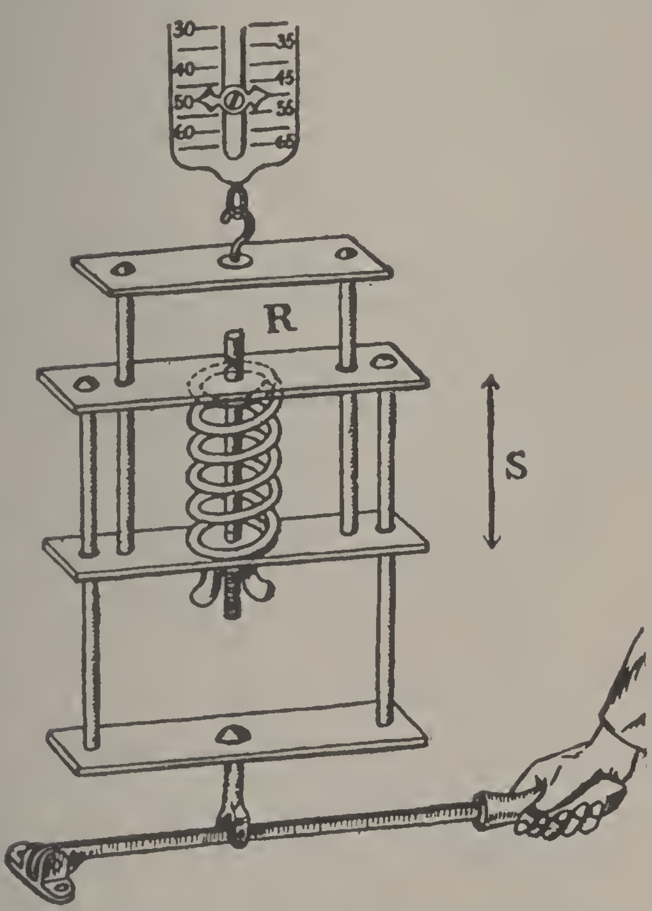

Fig. 31. Simple Rigging for Testing Valve Spring Pressure and Strength

If only a quick comparison of four springs is desired, the device can be made without the bottom lever, as the setting of *S* at a definite figure—say to a template of exact length—would call for a certain reading of the scale of the spring balance.

Cutting Valve Key Slots. Cutting valve key slots in valve stems is another mean job, which the repair man frequently meets. He runs across this in repairing old cars for which he has to make new valves and at other times. The best plan is to make a simple

jig which will hold, guide, and measure, doing all these things at once as all are important. Such a jig is shown in Fig. 32. It consists of a piece of round or other bar stock, in which a central longitudinal hole is drilled to fit the valve stem, one end being threaded for a set screw. Near the other end of the jig, three holes are drilled in from the side, of such a diameter as to correspond with the width of key slot desired. These are so placed that the length from the top of the upper hole to the bottom of the lower gives the length of key seat desired. Opposite the three drilled holes and at right angles to them another hole is drilled and tapped for a set screw.

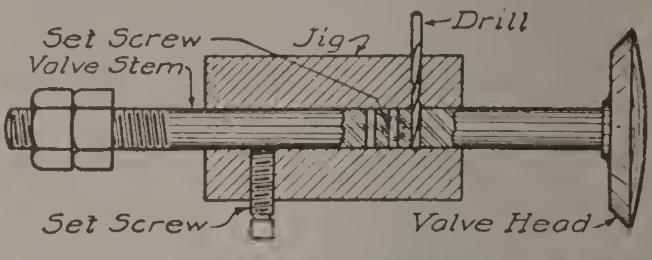

Fig. 32. A Jig for Slotting Valve Stems Which Can Be Made for a Few Cents

To use the device, slip the valve in place and set the bottom screw of the jig so as to bring the three drilled holes at the correct height for the location of the key seat. Then the three holes are drilled, and the valve is moved upward so that the space between the holes is opposite a guide hole, and two more holes are drilled to take out the metal between. The five holes will give a fairly clean slot, which only needs a little cleaning up with a file, before using.

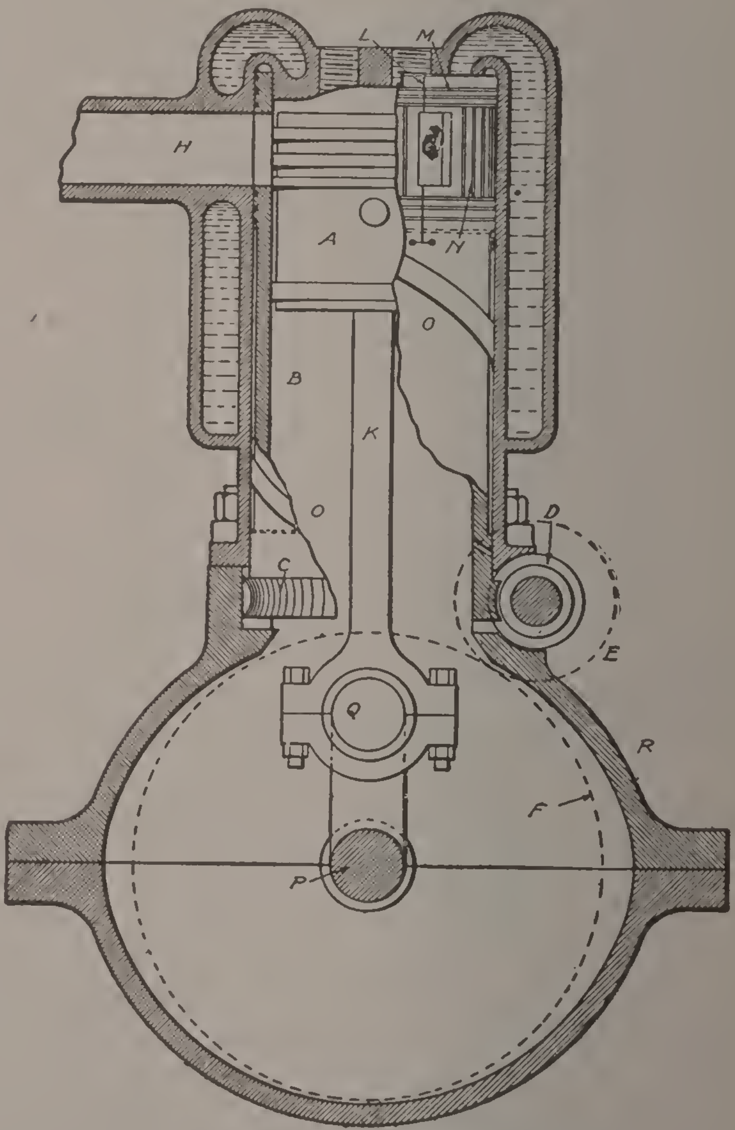

Fig. 33. Section through Ledru (French) Camless Engine. The Rotary Gear-Driven Sleeve Displaces All Cams

SLIDING SLEEVE VALVES

A method of avoiding cams, and with it all cam troubles, is the use of a sliding sleeve in place of a valve, slots in the sleeve corresponding to the usual valve openings, both as to area

and timing. The sleeves may be operated by means of eccentrics, by various lever motions, or by a direct drive by means of a gear.

Gear Control. An example of the application of a worm and gear for this purpose to a French two-cycle engine is shown in Fig. 33, although there is nothing in its construction which would prevent its use on the more usual four-cycle engine.

In this figure, *P* is the usual crankshaft, *Q* the large end of the connecting rod *K*, while *A* is the piston and *R* the crank case, no one of these differing from those in other engines. On the crankshaft there is a large gear *F*, which drives a smaller gear *E*, located on a longitudinal shaft above and outside of the crank case. On this shaft is located a worm gear *D*, which meshes with a worm *C* formed integral with the sleeve surrounding the piston *B*. Aside from this worm gear, the sleeve is perfectly cylindrical, being open at both ends. It is placed outside of the piston, between that and the cylinder walls. At its upper end, it has a number of ports or slots cut through it, which are correctly located vertically to register or coincide with the port openings in the cylinder walls, when the sleeve is rotated. At *H* is seen one of these—the exhaust, while 90 degrees around from it, and hence invisible in this figure, is a similar port for the inlet. As the crankshaft rotates, the side shaft carrying the worm is constrained to turn also. This turns the worm which rotates the worm wheel and, with it, the sleeve. Thus the openings in the sleeve are

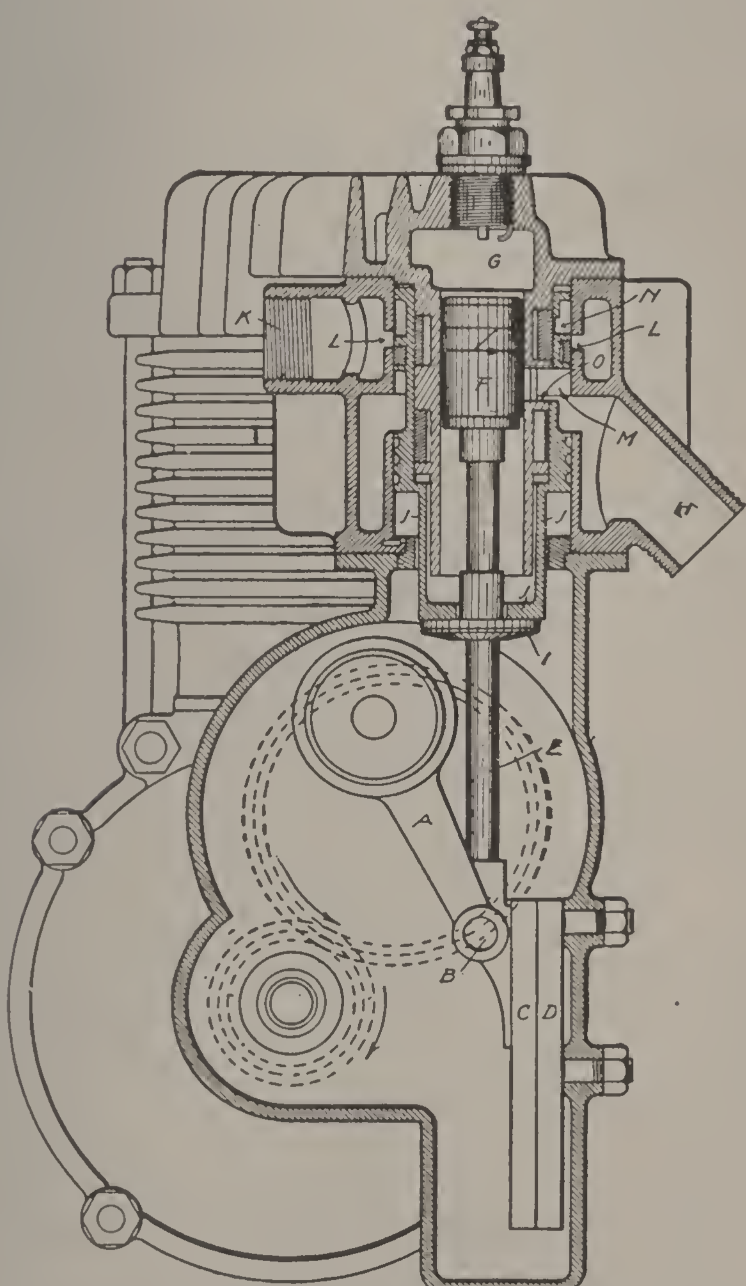

Fig. 34. Osborn Valve Motion without Cams

brought around to the proper openings in the cylinder and the combustion chamber is supplied with fresh gas, the burned gases being carried away at the correct time in the cycle of operations.

With a motor of this sort, the greatest question is that of lubrication. The manner in which it is effected in this case is by means of the large wide spiral grooves shown at *OO*, and the smaller circular grooves at the upper end *M*. This problem is also rendered more easy of solution by the machining of the sleeve, as during this operation much metal is cut away along the sides so that the sleeve does not bear against the cylinder walls along its whole length but only for a short length at the top and a still shorter length at the bottom.

Eccentric and Lever Control. The same result is accomplished by the use of a combination of eccentrics and levers, as is indicated in Fig. 34, showing the idea of a New York inventor, Osborn. This scheme places upon the usual cam gear an eccentric pin, upon which is located an eccentric rod or lever *A*. The latter is pivoted at its lower end to a pin *B*, which pin is a part of a sliding member *C*, carrying upon its upper part a piston rod *E*. This slide reciprocates, according to the impulse imparted to it by the eccentric *A*, being guided by the slides *D*, which are fixed to the side of the crank case.

Upon the upper end of the piston rod *E* is fixed a piston *F*, and slidably mounted around the whole is another piston valve *J*. The piston *F* is always moved by the rod, while the valve *J* is only moved upward by the collar at *I*, its downward motion being produced by a spring, not shown. *G* is the combustion chamber into which it is desired to lead the fuel mixture, and out of which the exhaust gases must afterward be taken, through the exhaust pipe *H*. *K* is the inlet pipe, *LL* are the inlet ports, and *M* is the exhaust port. Unfortunately, this drawing shows the piston at the top of its movement, which would be more clear were it at the bottom. On the down stroke of the inner piston, moved positively by the eccentric, the exhaust gases rush down and out. On the same stroke, the inflowing gas fills the passage around the outside of the piston, so that when the exhaust stroke is completed, and the piston has risen so as to uncover the lower edge of the port through the walls *O*, the gases are free to rush in, impelled by the suction of the motor piston. In the meantime, the rising outside sleeve has covered the exhaust port *M*, so that none of the mixture may escape to the outside air.

Knight Sleeve Valves. In the last few years, tremendous progress has been made here and abroad with the Knight motor, named after its Chicago inventor. In many important factories this has displaced those with the poppet form of valve. In this, a regular four-cylinder four-cycle engine, the valves consist of a pair

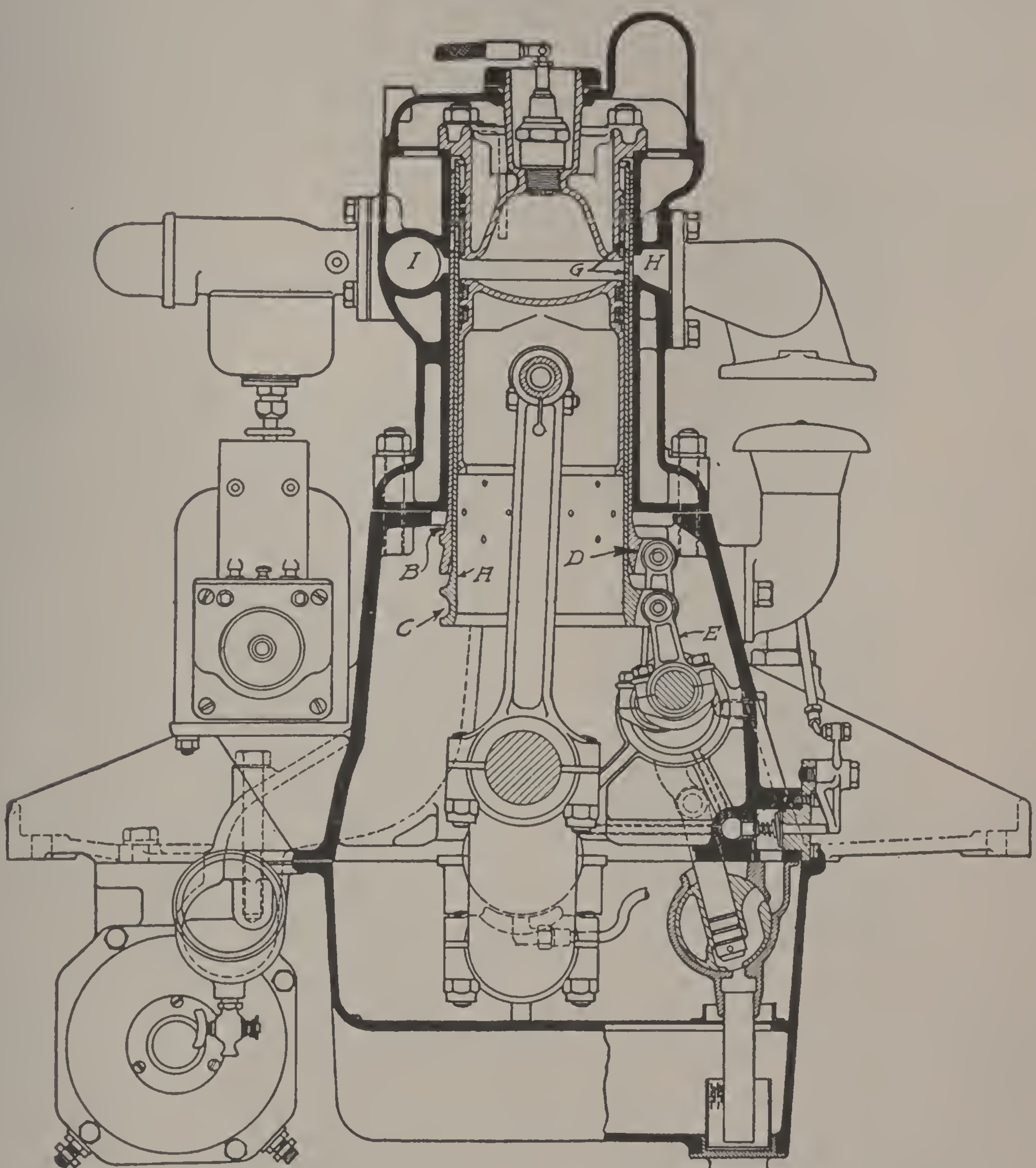

Fig. 35. Willys-Knight Engine in Which Eccentrics and Sliding Sleeves Replace Cams and Valves

of concentric sleeves, openings in the two performing the requisite functions of valves in the proper order. These sleeves, as Fig. 35 shows, are actuated from a regular camshaft—running at half the crankshaft speed and driven by a silent chain—by means of a series of eccentrics and connecting rods. In the figure, *A* is the inner and

TABLE I

Royal Automobile Club's Committee Report on Knight Engine

Motor horsepower—R. A. C.		38.4	22.85
Bore and stroke		124 by 130	96 by 130
Minimum horsepower allowed		50.8	35.3
Speed on bench test		1200 r.p.m.	1400 r.p.m.
Car weight on track		3805 lb.	3332.5 lb.
Car weight on road		4085 lb.	3612.5 lb.
Duration of bench test		134 hours 15 min.	132 hours 58 min.
Penalized stops		None	None
Non-penalized stops		Five—116 min.	Two—17 min.
Light load periods		19 min.	41 min.
Average horsepower		54.3	38.83
Final bench test		5 hours 15 min.	5 hours 2 min.
Penalized stops		None	None
Light load periods		15 min.	1 min.
Average horsepower		57.25	38.96
Mileage on track		1930.5	1914.1
Mileage on road		229	229
Total time on track		45 hours 32 min.	45 hours 42 min.
Average track speed		42.4 m. p. h.	41.8 m. p. h.
Fuel per brake horsepower per hour	First bench test	.679 pt.	.739 pt.
		.613 lb.	.668 lb.
	Final bench test	.599 pt.	.749 pt.
		.541 lb.	.677 lb.
Car miles per gallon	On track	20.57	22.44
	On road	19.48	19.48
Ton miles per gallon	On track	34.94	33.37
	On road	35.97	31.19

longer sleeve carrying at its lower end the groove or projection *C*, around and into which the collar actuating the sleeve is fixed. This collar is attached to the eccentric rod *E*, which is driven by the eccentric shaft shown. The collar *D* performs a similar function for the outer sleeve *B*.

At the upper ends of both sleeves, slots *G* are cut through. These slots are so sized and located as to be brought into correct relations to one another and to the cylinder ports, exhaust at *H* and inlet at *I*, in the course of the stroke.

It might be thought that the sliding sleeves would eat up more power in internal friction than would be gained, but a very severe and especially thorough test of an engine of this type, made by the Royal Automobile Club of England, an unbiased body, proved that for its size, the power output was greater than that of many engines of the regulation type. Moreover, the amount of lubricating oil was small.

The results of the test are shown in Table I. After the test

was concluded, both of the sleeves, Fig. 36, were found to show still the original marks of the lathe tool. This proved conclusively that the principle of this type was right, for the tests were equivalent to an ordinary season's running.

Referring to Fig. 36, the slots which serve as valve ports are at *G*. The longer sleeve *A* is the inner one. At the bases of the sleeves are the collars and pins *D* by which the connecting rods are attached. The surfaces of the valves are grooved at *J* to produce proper distribution of oil.

Fig. 36. Sleeves Which Replaced Valves on Knight Engine, after 137-Hour Bench Test and 2200 Miles on the Road

The Knight type of motor has been adopted by a number of well-known firms in America such as the Stearns, Willys, F. R. P., Brewster, and Moline Companies. These engines are noted for their silent running and for their efficiency. The Moline-Knight motor was in January, 1914, subjected to a severe continuous-run test of 337 hours under the auspices of the A. C. A. authorities. During this time the motor developed an average of 38.3 brake horsepower. For the 337th hour the throttle was opened and the motor developed a higher speed and a brake horsepower of 53. The test gives abun-

dant evidence of the endurance and reliability of the sleeve-valve type of motor and of the sterling qualities of the product of the American automobile manufacturers. After the test the motor parts showed no particular evidence of wear.

In addition to the four-cylinder forms just mentioned, the Knight type of motor is also made as a six, and more recently, as a V-type eight. In these forms, the basic principle of sliding sleeves and their method of operation and timing is not changed.

Originally, the Knight motor was installed only in the highest class cars. The firms in Europe which took it up ranked among the very first—notably the Daimler, Panhard, Minerva, etc.—but in this country it has made little progress among the better cars, and now it is assuming the rank of a low and medium priced motor, being available for about $1,000, and as an eight for approximately $2,000.

ROTATING VALVES

Successful Operation Requires Two Valves. In addition to rotating and reciprocating sleeves and reciprocating valves, the rotating valve has been tried, in common with any number of other devices intended to supplant the ordinary poppet valve. This arrangement on a multicylinder motor consisted of a single valve for all the cylinders, which extends along the top or side of the cylinder head and is driven by shaft, chain, or otherwise, at one end. Naturally, this necessitated having the ports cut very accurately in the exterior of the valve, or rather the sleeve—for it usually assumed the form of a hollow shell—for not alone did it act as inlet and exhaust manifold but also as the timing device. This multiplicity of functions seems to have been its undoing, for the latest types using valves of this form have no longer one shell as at first, but a pair, one for the exhaust valves and one for the inlet valves. In the latter shape these have been more successful, but not sufficiently so to bring them into competition with the poppet and Knight sleeve valve forms.

Roberts Rotary Valve. A motor—a two-cycle motor by the way—which has been very successful in motorboat and aeroplane work although not much used for motorcars, is the Roberts, shown in Fig. 37, with the valve in Fig. 38. This valve is for the inlet

ports only, and is located inside the crank case, while the cylinders exhaust freely into the open air, the exhaust issueing directly from the cylinders.

MISCELLANEOUS MOTOR REPAIR WORK

Cylinder Heads. A great many motors have detachable heads and their quick removal is a great convenience, when there is carbon

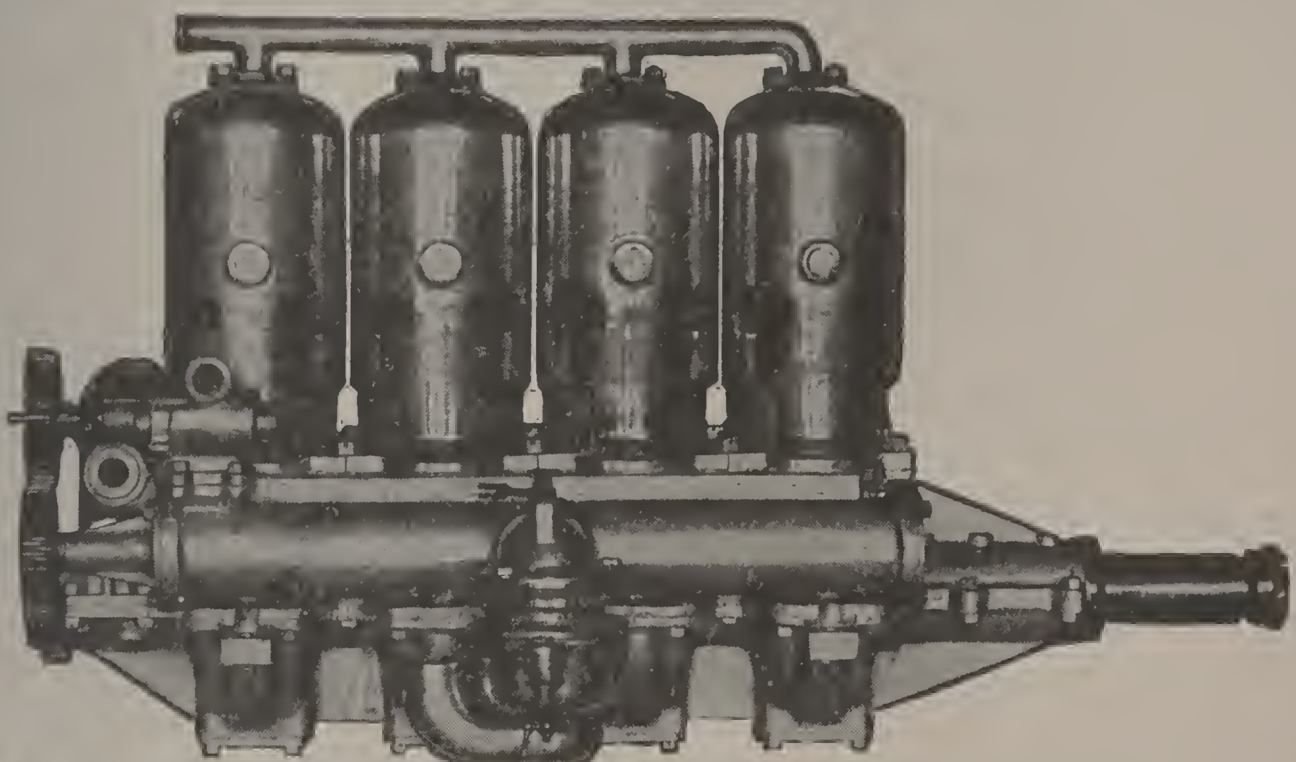

Fig. 37. Roberts Two-Cycle Motor with Rotating Crank-Case Valve
Courtesy of E. W. Roberts, Sandusky, Ohio

to be scraped off, pistons to be looked over, or other internal work to be done. However, replacing them is never quite so easy as removing them, partly on account of the cylinder heads themselves and partly on account of the pistons. The latter are particularly troublesome when the cylinder head is hinged. The cylinder head

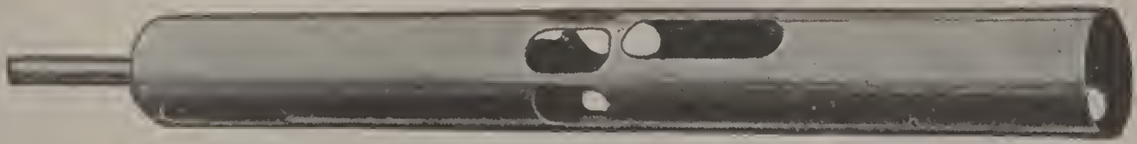

Fig. 38. Rotating Inlet Valve of Roberts Two-Cycle Motor

should be replaced with great care, and after replacement it is fully as important to bolt it on properly. If one bolt or a series of bolts is tightened too quickly and too hard, it is likely to result in cracking the cylinder casting or the head casting or both.

Proper Method of Bolting on Head. Usually on an **L**-head type of motor, there are three rows of bolts for the cylinder head—one

row along the middle, screwing into one side of the cylinders; another row screwing into the other side of the cylinders; and a third along the valve side. These should be tightened in order: first the middle bolts of the middle line, working out to the ends; next, in turn, the middle bolts of the back of the cylinder, the middle bolts of the valve side, the ends of the cylinder, and, finally, the end bolts on the valve side. All these should be tightened but a few turns at a time, and after all are down, a second round should be made in about the same order, to give each bolt a few more turns. In this way the cylinder head casting, which is both large and intricate, is slowly pulled down to the cylinder straight and true so that it is not warped or twisted. Moreover, if the cylinder is pulled down straight in this manner, all the bolts can be tightened more than if the first bolt were tightened very much, for that would result in cocking up the opposite side so that the bolts there could not be properly tightened.

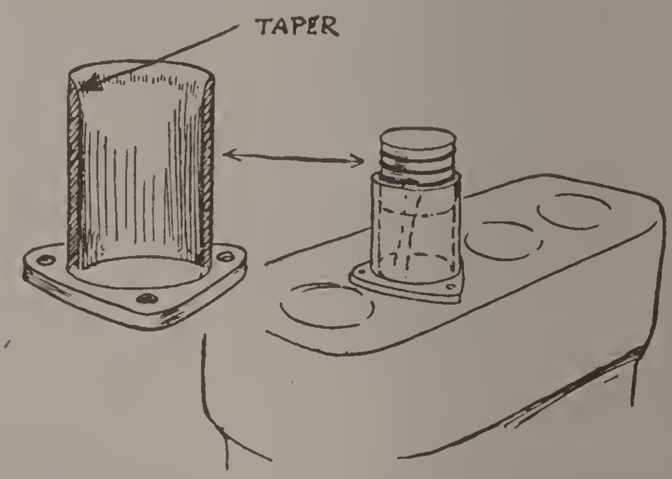

Fig. 39. A Simple and Easily Made Jig for Replacing Pistons in Detachable Head Motors

Rigging for Replacing Piston. In motors of the detachable head type, like the Willys shown in Fig. 35, the Chalmers, Briscoe, and others, the work of replacing the pistons, particularly if the crank case is cast integral with the cylinder block, is considerable. In fact it is sufficiently difficult to warrant making a special jig for guiding the pistons down into the long cylinder bores; this fastens onto the top of the cylinder where the head belongs.

As shown in the sketch, Fig. 39, the jig consists of a round shell, the interior of which is at the bottom of the same bore as the cylinder, but flares out considerably at the top. The base consists of the flange needed for turning this in the lathe, and may be of any shape, size, and thickness. The action of the enlarged diameter at the top, gradually reducing to the exact cylinder size at the bottom, is to hold the piston rings in place and slowly contract them as the piston is lowered, so they pass down into the cylinder bore without trouble. One casting must be made for each cylinder bore, but the

time and trouble which they save and the injuries to workmen and parts which they avoid make them well worth while.

Speeding up Old Engines by Lightening Pistons, Etc. As has been pointed out previously under Cams, one way to speed up an old engine is to replace the old camshaft and cams with new ones giving more modern timing. Another and a less expensive and troublesome way in which this can be done is by lightening the pistons and reciprocating parts. This the repair man will surely be called upon to do, as the manufacturer probably would refuse.

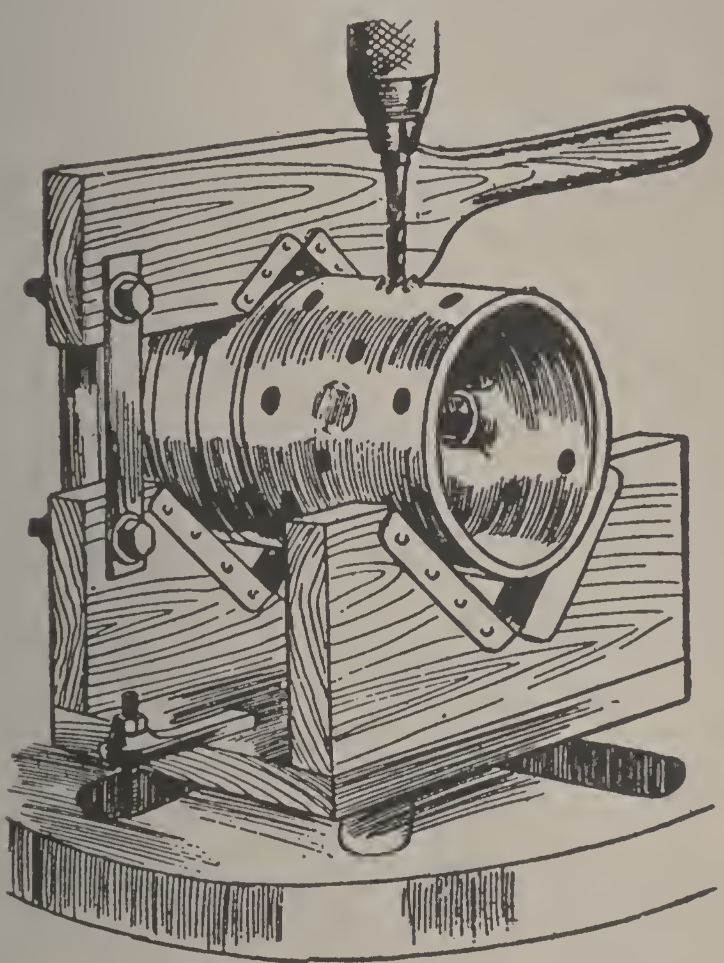

Fig. 40. A Home-Made Wooden Stand to Facilitate Drilling Out Pistons

In order to get out any amount of metal worth the trouble, it will be necessary to drill from 12 to 20 or more holes of from $\frac{1}{2}$-inch up to 1-inch diameter, depending upon the size of the piston as to bore and length. In a six-cylinder motor, this amounts to almost 100 holes (even more in some cases), and as these must be drilled with considerable similarity in the pistons, it is well worth while to construct a fixture to aid or speed up this work.

Clamp for Pistons. The first requisite is a clamp, Fig. 40, to keep the piston from turning, so that it will not break the drill. A good way to begin is to construct a base with a pair of uprights having deep 90-degree V's in them, this being made so that it can be bolted to the drill-press table. The V's should be lined with leather or fabric, and for this purpose discarded clutch or brake linings answer very well. To one of the uprights is pivoted a long handle, having a lined V which matches with that of the upright below it and gives a good grip on the piston.

Drilling Holes. When drilling to save weight, the holes are put in close together, and in regular form, the idea being to take out

as much weight of metal as is safe. In doing this it is well to work out a scheme of drilling in advance and to make a heavy brown paper template, fastening this to each piston in turn. It is not advisable to remove in the first instance all the metal possible, but only enough to show the benefit of the method; after it has proved satisfactory, the first job may be improved upon later. For instance, in lightening pistons it is a good plan to use a $\frac{3}{4}$-inch drill the first time and not to put in too many holes. If this proves satisfactory and the owner comes back for more, you can go over the same lot of pistons, using a $\frac{1}{2}$-inch or $\frac{3}{8}$-inch drill between the existing holes, and thus reducing the weight of the lower end of the piston to its lowest possible point.

Curing Excessive Lubrication. *Holes in Cylinders.* When it comes to drilling holes, to provide an outlet for the excess oil in the cylinders and so to reduce smoking, small holes, $\frac{1}{4}$-inch for example, are sufficient and may be drilled in on any spiral plan, simply beginning near the bottom and working up close to the piston pin bosses along a spiral track. The advantage of the spiral arrangement is that no hole is above another; the dripping from each hole is therefore distinct and the quantity which runs down is greater.

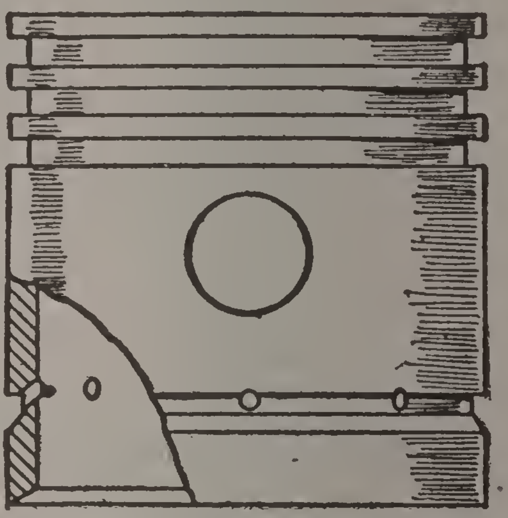

Fig. 41. Method of Grooving and Drilling Piston to Overcome Excessive Lubrication and Smoking

Grooving Pistons. Another method of curing the excessive lubrication to which the older cars—particularly those with splash lubrication—are subject, is to turn a deep groove in the bottom of the piston, about like a piston ring groove but with the lower edge beveled off. When this is done, much as shown in Fig. 41, a series of small holes—made with about a No. 30 drill—are put in at the angle of the bevel; 6 or 8 holes, equally distributed around the circumference, are probably enough. The sharp upper edge acts as a wiper and removes the oil from the cylinder walls into the groove, whence it passes through the holes to the piston interior, and there drops back into the crankcase. No ring is placed in the slot as it would prevent the free passage of the oil. This device stops the smoking immediately.

Piston Troubles. *Frozen or Clogged Pistons.* Sometimes, the pistons will apparently be frozen in the cylinders, particularly in very cold weather and when fairly thick oil is used. This is but a temporary trouble and can be cured by pouring in a thin oil or, better yet, kerosene. The thin oil will work more quickly if heated, and should be poured in on top of the pistons, either through the petcock, valve-cap opening, or other available opening in the top of the cylinder. Being thin—and if hot, thinner than usual—the oil will work down between piston and cylinder walls, cutting through the thicker oil which has hardened there under the influence of the cold weather, and thus will free the pistons.

Loose Pistons. Many times the pistons will wear just enough so that they are loose in the cylinder all the way around. This causes leakage of gas, piston slaps, and other similar troubles. If the owner of the car does not care to buy new pistons, or if the car is an "orphan", or if, for other reasons, pistons cannot be obtained, the clever repair man can remedy the trouble at small expense. The process consists in heating and expanding the old pistons. The heating is done in charcoal and must be done very carefully and slowly. After the pistons become red hot the fire is allowed to go out slowly, so that the piston is cooled in its charcoal bed. Sometimes as much as $\frac{4}{1000}$ of an inch can be gained in this way. When the pistons are so far gone that they cannot be handled in this way, they must be replaced with new ones.

Use of Oversize Pistons with Worn Cylinders. When the cylinders have worn so as to require grinding out, or when scoring necessitates this, oversize pistons must be used. In the majority of factories having any kind of system, three oversizes are made $\frac{4}{1000}$-inch over, $\frac{8}{1000}$-inch over, and $\frac{11}{1000}$-inch over. The first provides for the initial grinding-out of the cylinder, the second for the second grinding, and the third for a lighter, final grinding. Beyond this, it is considered, the cylinder will be too thin to warrant further grinding; moreover, by the time three cylinder grindings have been lived out, the balance of the car will doubtless be too far gone to justify further cylinder repair work. Many factories, particularly those making a very light-weight car where thicknesses everywhere are kept down to the limit, allow but two oversizes, and thus, two grindings.

CLUTCH

Classification. Principal among the indispensable parts intervening between engine and road wheels, and one which may be a source of great joy or correspondingly great wrath, according to whether it be well or poorly designed and fitted, is the clutch. There are six forms into which clutches may be divided, although not all of them are in general use in the automobile. These different forms are:

(1) Cone clutches
(2) Band or drum clutches
(3) Expanding ring clutches
(4) Disk and friction clutches
(5) Hydraulic or fluid clutches
(6) Magnetic or electric clutches

In general, only the first four of these six forms of clutches are used on automobiles and in fact the number of adoptions of the cone and disk clutches so far outnumber the others that they practically exclude the other types. The hydraulic type is used mainly on commercial vehicles and the magnetic type was also developed first on heavy trucks. Within the last few years, however, a magnetic clutch has been placed on a touring car and bids fair to become popular. Further discussion of this will be given later.

The necessity for a clutch lies in the fact that the best results are obtained in an automobile engine when run at constant speed. Inasmuch as the speed of the car cannot, from the nature of its use, be constant, it requires some form of speed variator. This is the usual gear box or transmission, but in addition, there is the necessity of disconnecting this from the motor upon starting, since the engine cannot start under a load. There is also the necessity for disconnecting the two when it is desired to change from one speed to another either by way of an increase or a decrease. So, also, when one wishes to stop the car, there must be some form of disconnection. There are then three real and weighty reasons for having a clutch.

Cone Clutch. *Single Cone Type.* This consists of two members, one fixed on the flywheel or other rotating part of the engine, the other fixed to the transmission shaft. The latter usually slides upon the shaft so as to allow engagement and disengagement. A spring holds the two together or apart, according to the type of clutch used.

When the smaller-diameter member is spoken of, it is usually called the *male member,* while the part of larger size is spoken of as the *female member.*

The cone type is found to be made in two different varieties; the one in which the male member enters the female naturally at the open end is called the *direct* cone type. In the other form, the male is set within the structure of the female and is pressed outward toward the open end to engage it. This is called the *inverted,* or sometimes the *reversed,* cone clutch.

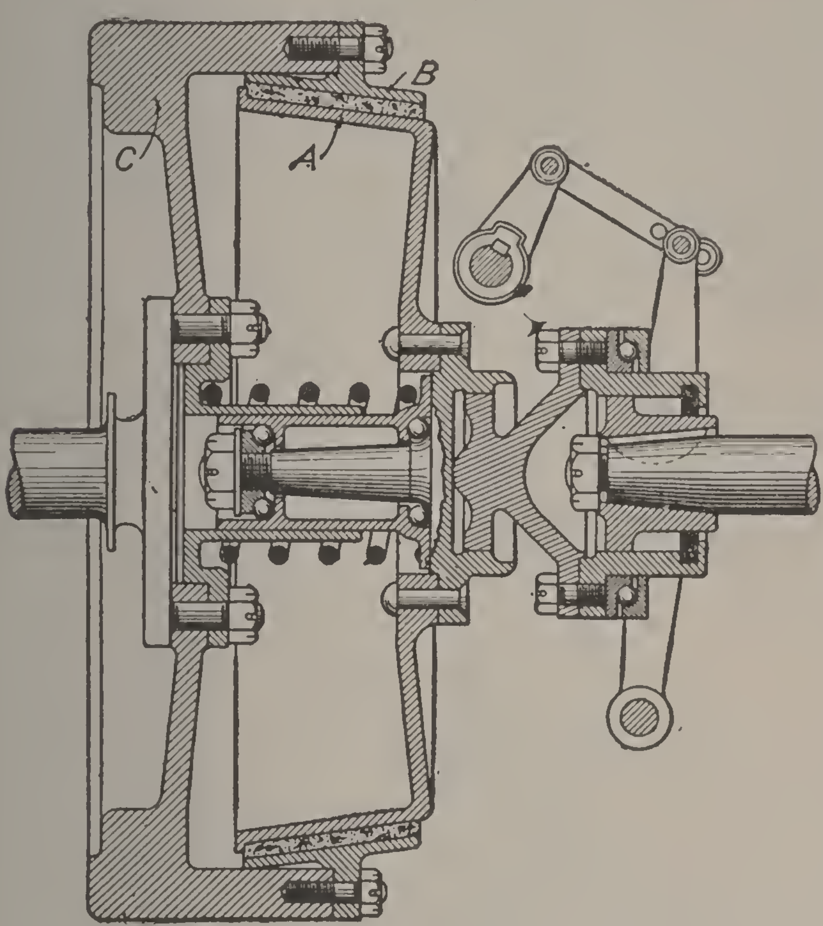

Fig. 42. Typical Reversed Cone Clutch

A great disadvantage of the inverted form is that the spring must be carried between the two cones, which means that it is inside where it cannot be reached for adjustment. Fig. 42 shows this clearly. This form causes trouble in assembling because the male cone *A* must be put in place with the spring between it and the flywheel *C*, before the female *B* can be set into its place and bolted up. These two big sources of trouble have caused designers to turn to the direct type more freely, as it lends itself readily to an external adjustment. If the spring is outside, it is easily put into place and as easily taken out. Fig. 43, which illustrates this, is a section through the Bayard (French) clutch, and the spring is seen to be entirely outside the clutch proper. Its location is such as to permit the adjustment of the tension at any time, by means of a screw collar *C*, which may be done with no more trouble than lifting up the footboard of the car and turning the collar forward a few turns.

Not all designers have hit upon as happy a solution of the clutch problem as this. Thus, in the Studebaker clutch, shown in Fig. 44, the spring *B* is external to the clutch but so placed that it is

necessary to disconnect the universal joint A^1A, take it off the car, loosen a set screw, adjust, and then repeat the other operations in reverse order. A similar state of affairs is found in the Benz, illustrated in Fig. 45, in which it is necessary to take out the bolts connecting the shifting collar to the male member, and then, through the longitudinal motion permitted by the form of universal joint used, slide this backward as far as possible. The latter movement allows of removing it from place, then the spring tension may be adjusted by simply removing a cotter pin and the nut it holds.

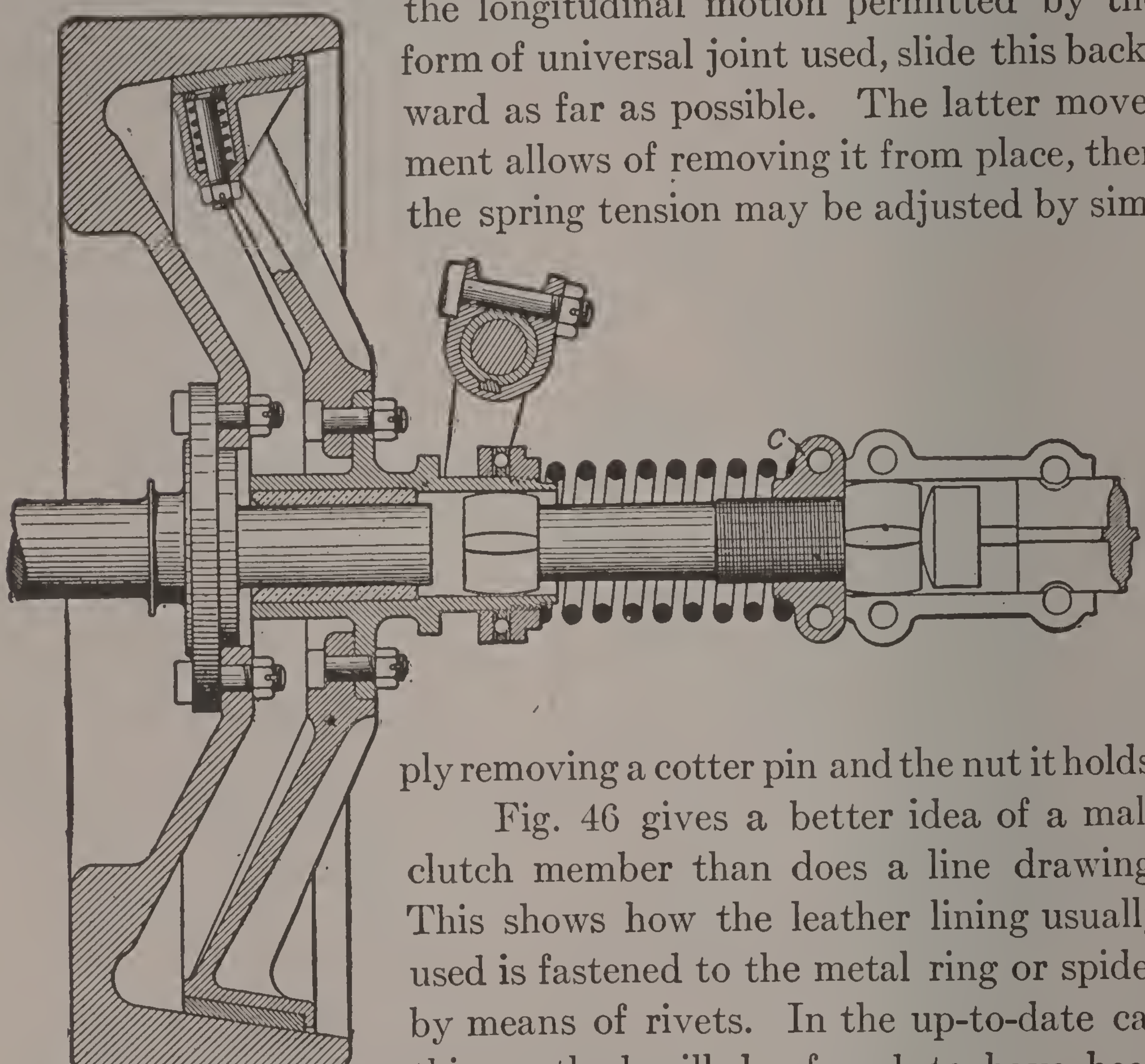

Fig. 43. Bayard (French) Direct Cone Clutch

Fig. 46 gives a better idea of a male clutch member than does a line drawing. This shows how the leather lining usually used is fastened to the metal ring or spider by means of rivets. In the up-to-date car this method will be found to have been carried even farther than this, the leather being put on in sections, so that in case of unequal wear a single, worn-out section may be replaced without disturbing the others. An even later idea emanates from England, and is nothing less than putting these sections onto the cone by means of dovetails. In this way a worn section can be replaced in the length of time that it takes to tell about it.

Double and Triple Cones. A prominent German maker has been very partial to the double-cone form of clutch, particularly for large and high-powered cars. This has generally consisted of a pair of single direct clutches set back to back, and coupled up in such a way

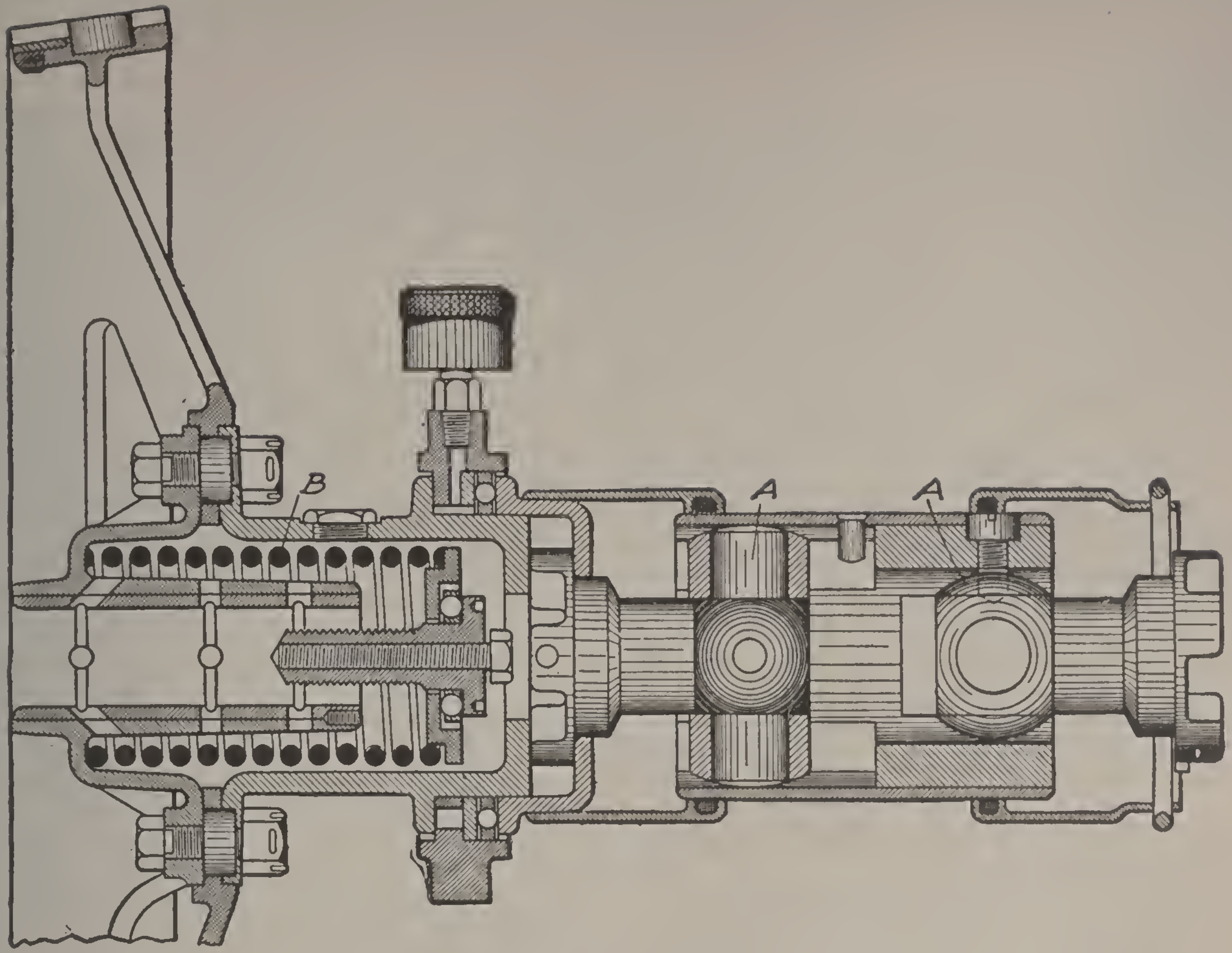

Fig. 44. Studebaker Direct Cone Clutch
Courtesy of Studebaker Automobile Company, South Bend, Indiana

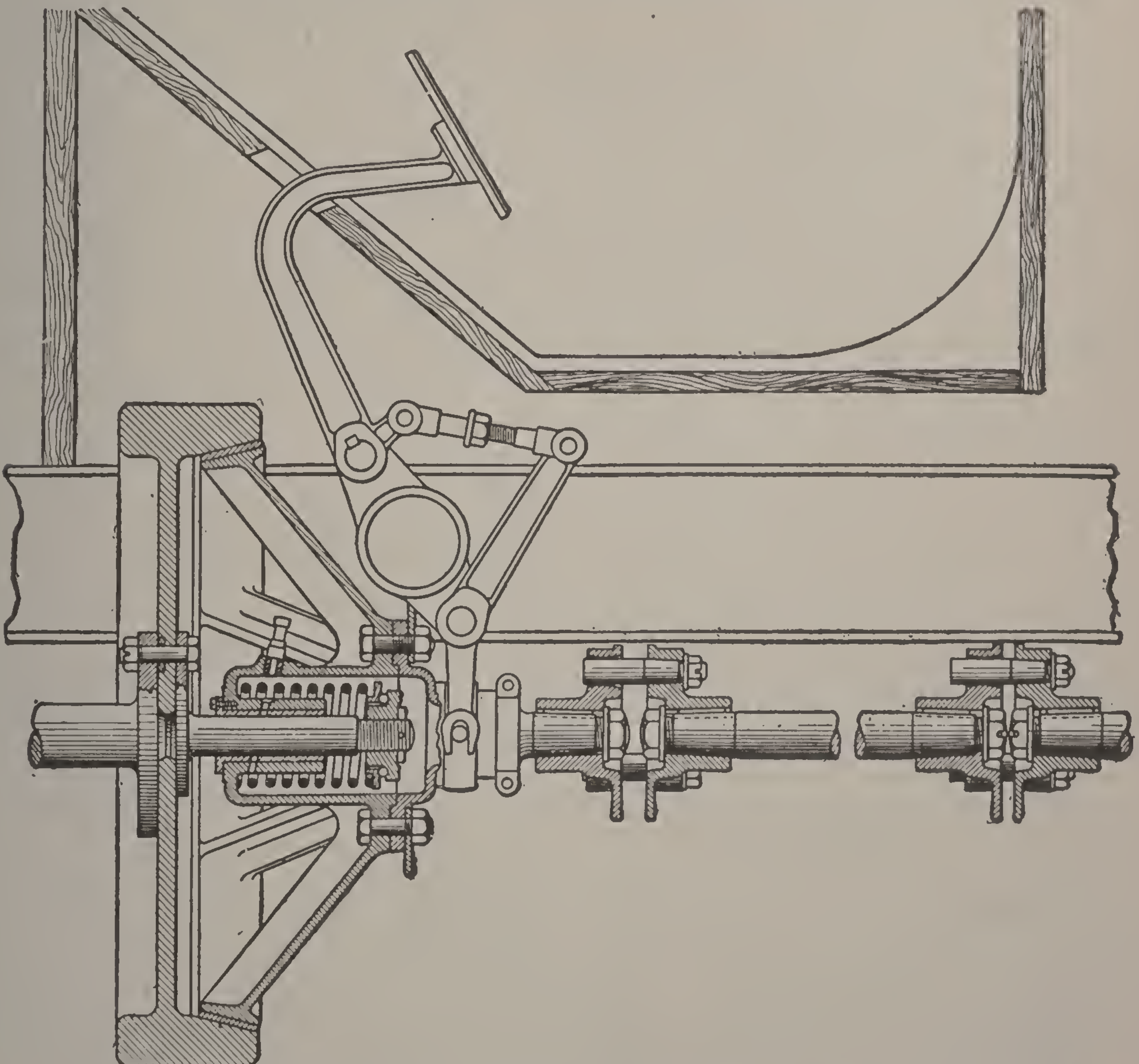

Fig. 45. Benz (German) Cone Clutch with Somewhat Inaccessible Clutch Spring

that pressure on the pedal acted upon the two progressively; that is, they were engaged one after the other. Conversely, the initial declutching pressure worked gradually upon one until that was entirely out of engagement, when a continued pressure would gradually throw out the other. For very large motors, this has a distinct advantage in that the speed can be temporarily reduced by applying the clutch pedal part way. In this case one of the two clutches is thrown out, and the one left, not being able to carry all the motor power, slips and thereby reduces the speed. A quick pick-up and very rapid acceleration can then be had, when the need for reduced speed is removed, by simply dropping in the second clutch.

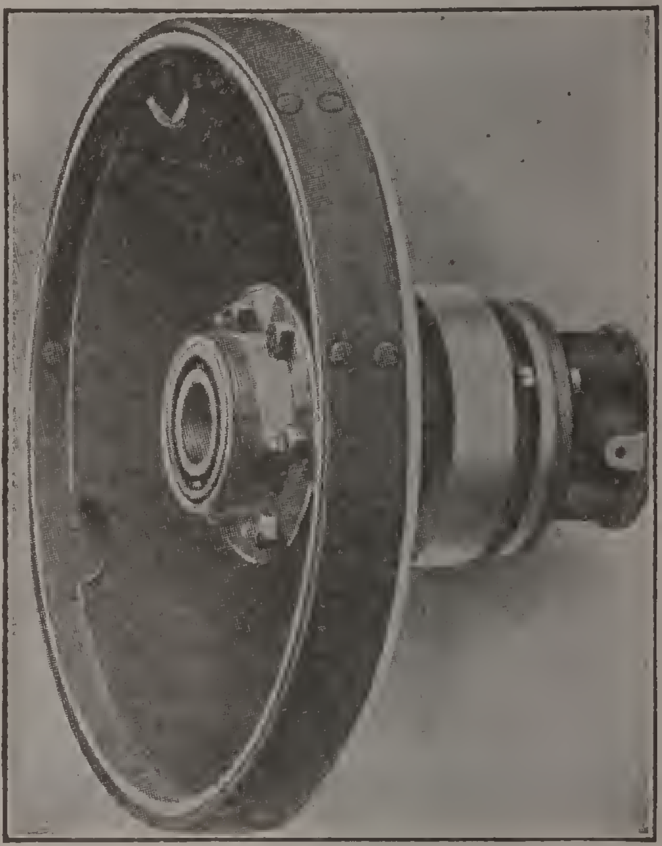

Fig. 46. Male Portion of Clutch Using Narrow Leather to Carry Load

Somewhat the same idea is presented in the triple cone clutch shown in Fig. 47. This has three different sizes of cones, each one meshing, or contacting, with a smaller section of the cone housing. All three are on the same splined shaft, and the arrangement is such that each part has its own spring, and thus is self-contained. When the clutch collar is pushed to the left, the smaller cone is disengaged. A further movement of about $\frac{3}{16}$ inch and its hub comes in contact with the hub of the middle-sized cone, a continued movement disengaging it. Similarly with the third cone.

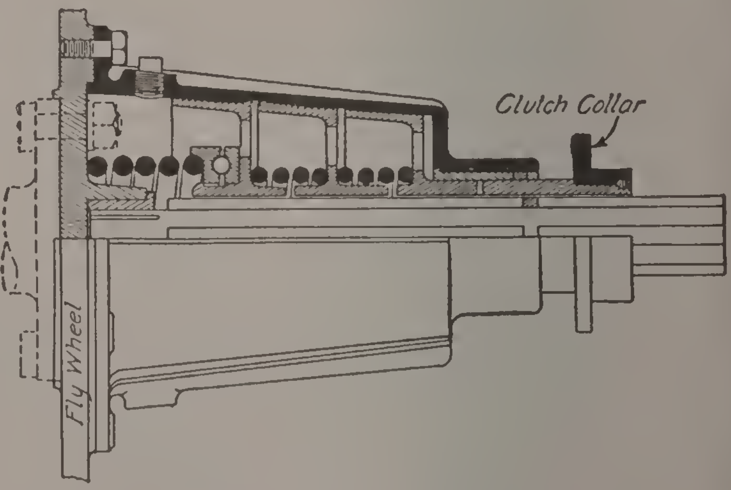

Fig. 47. New Type of Triple Cone Clutch

The reverse action takes place on engagement, the larger part clutching first, then the intermediate, and lastly the small cone. In this way, a smooth and gradual action is obtained. The facing

is plain metal, which contacts with metal on a 4-degree taper. It runs in oil. The over-all length is but $11\frac{7}{8}$ inches for a 35-horsepower unit.

Requirements Applying to All Clutches. In a serviceable clutch there are two general requirements which are applicable to all forms. These are *gradual engagement* and *large contact surfaces*, although the latter requirement may be made to lose much of its force by making the surfaces very efficient. In the cone clutch, gradual engaging qualities are secured by placing a series of flat springs under the leather or clutch lining. By means of these springs, acting against the main clutch spring, the clutch does not grab, since the large spring must have time in which to overcome the numerous small springs. In this way the engagement is gradual and the progress of the car is easy as well as continuous.

The specific necessity in a cone clutch, whether it be direct or inverted, is a two-fold one—*sufficient friction surface*, and *proper angularity*. As the latter, in a way, effects the former, as will be discussed more in detail later, this really reduces to one complex requirement.

The angularity varies in practice from 8 to 18 degrees. In arriving at these figures, a line of reasoning is followed somewhat like the following:

The force of the spring acts along one leg of a right triangle of which the resulting useful force is found to lie along the hypothenuse, the latter being perpendicular to the surface of the clutch. In this case, the ratio of the resulting useful force x to the original spring pressure A is the ratio of 1 to the sine of the angle of the clutch cone θ. Expressed in the form of proportion, it is

$$x:A::1:\sin\theta$$

or as an equation

$$\frac{x}{A}=\frac{1}{\sin\theta}$$

Since 1 is a constant, reducing $\sin\theta$ increases the ratio. Reducing the sine, in turn, means reducing the angle itself, and this is the course usually pursued as a large ratio is desired. For this reason small clutch-cone angles are used. The actual angle is, however, partly determined from another basis.

Coefficient of friction is the name given to the adhesion of two materials one to the other, under just such conditions as are described above. Since it is impossible to have perfect adhesion, this coefficient

is always less than unity. Now, the angle of the cone of a cone-type clutch is dependent solely upon the coefficient of friction of the materials selected and the condition of the friction surfaces. Quite frequently, in fact, usually, the materials of cone clutches are leather and cast iron; i.e., the female cone is either a part of a cast-iron flywheel or made of cast iron, while the male cone is usually some other material lined with leather. The ordinary male cone is of very light metal, so as to reduce the spinning action of this rapidly rotated mass. Of late years, aluminum has met with favor for this part.

The coefficient of friction for cast iron and leather has been determined as .30 dry, and .25 greased. Since the latter case is more usual this value will be used. Expressed mathematically, the coefficient of friction is the tangent of the angle of repose, so for this value it would be the angle of which .25 is the tangent. This is 14 degrees. A more conservative value of the coefficient is .20, for which the angle is but 11 degrees.

In the design of the clutch, however, a more accurate method than this is pursued. The twisting moment in foot-pounds M is equal to the horsepower P, reduced to foot-pounds, divided by the speed at which the power is to be transmitted. This gives the equation

$$M = \frac{P\,33{,}000}{2\pi R}, \text{ or roughly, } \frac{P\,5250}{R}$$

Let S represent the torsional resistance, to which the clutch must at least be equal, and F the mean or average radius of the male cone in inches

then $$S = \frac{P\,63{,}000}{F\,R}$$

If, now, the resulting pressure from the clutch spring acting normal to the clutch surface is z, the axial pressure or total exerted by the spring is x, and the coefficient of friction is f, then

$$z = \frac{x}{\sin\theta} \text{ and } S = zf = \frac{x\,f}{\sin\theta}$$

Equating the two values for S, and solving for x

$$x, \text{ spring pressure} = \frac{P\,63{,}000 \sin\theta}{F\,R\,f}$$

and solving for P

$$P, \text{ power transmitted} = \frac{x f F R}{63{,}000 \sin\theta}$$

Contracting-Band Clutch. A short consideration of the band style of clutch shows that this does not differ radically from the ordinary band brake, either in construction, application, or actual working. The difference in the two lies in the fact that the band, as a clutch, is designed to transmit power with as little loss as possible, while the band as a brake is designed to absorb the forward energy of a moving vehicle (equal in the last analysis to power) in the shortest possible space of time, i.e., to waste as much power as possible.

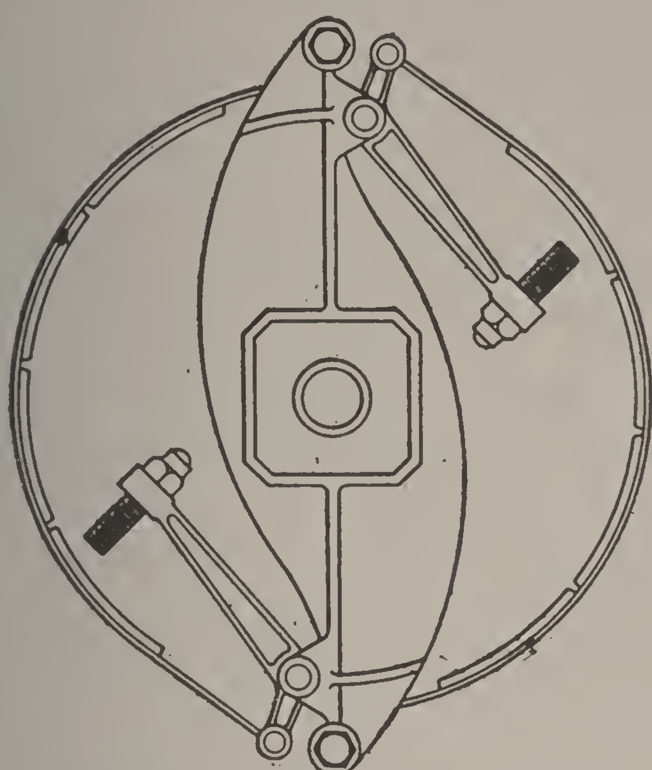

Fig. 137. Mors (French) Contracting-Band Clutch

Fig. 48 shows the form of band clutch used on the Mors (French) cars. In this form, the band is in two parts, and a rocker arm moved by a sliding cone operates the free ends of the two bands, which thus contract upon

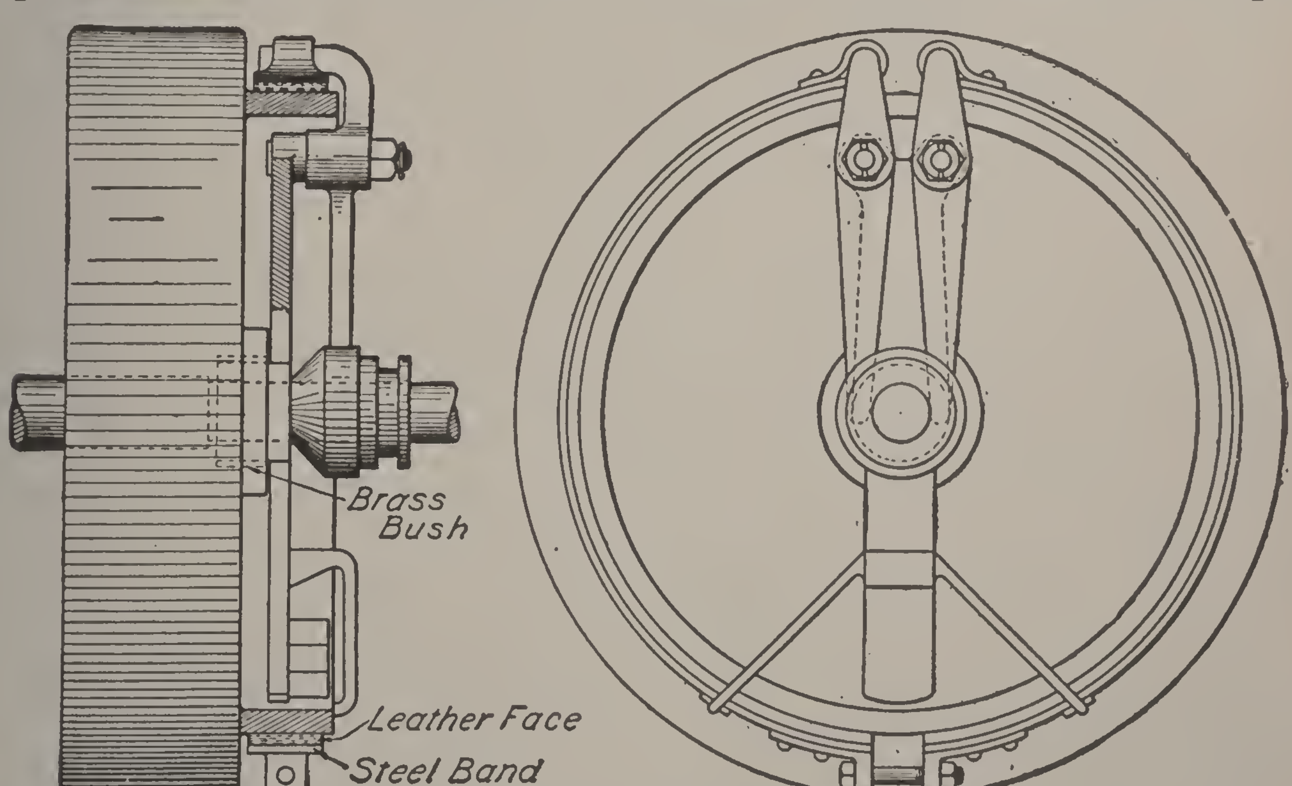

Fig. 48. Typical Contracting-Band Clutch

the clutch drum. Fig. 49 is the clutch which was used on Gaeth cars, made in Cleveland, Ohio. While not differing radically

from the Mors, this has the two parts or sections of the band united at the bottom and two operating levers are pivoted at the top, where a single conical-shaped cam moves both outward and tightens the bands on the drum.

The usual place in which the band clutch is found is in connection with a planetary transmission. There the band is always used, and there it reaches its simplest form, that of the plain band wrapped around the drum. One end is fixed and the other attached to the braking, or more correctly the clutching lever. A plain pull on this effects the clutching action. A more modern and more efficient form has one end of the band attached to one extremity of the clutching lever, while the other end of the band is fastened to the middle of this lever. The clutching pull comes upon the upper extremity of the lever. Then the band might be said to aid in clutching itself, i.e., a scissors action is obtained, and the required pull is lessened.

This principle is used in the Ford car, the planetary transmission being located just forward of the contracting bands and clutch disks. This is of particular interest as Ford is now the only American maker using the planetary form of transmission, all other makers, even of very low-priced machines—some below the Ford price—having gone to the selective sliding gear form.

When the band is used as a brake the pull necessary to stop the car is

$$p=fw\frac{D}{d}$$

in which f is the coefficient of friction, w the weight to be stopped, D the diameter of the road wheels, and d the diameter of the brake drum. Now the ratio of the diameter of the road wheels to that of the drum is but the ratio of the work arm to the power arm, so when the band is used as a clutch, the ratio of the radius of the two arms may be substituted. The power arm is taken as unity and the work arm as the radius of the clutch drum. Since this divided by 1 remains the same, it may be substituted in the formula above. So, too, with the weight, in place of this must be substituted the power to be transmitted, which is the equivalent of the weight in the other case. The formula then becomes

$$p'=fPr$$

Owing to the winding action of the band, the pull p' will be less than the pull p, by an amount which varies as the portion of a circle or number of degrees encircled by it. Then taking θ as the number of degrees

$$\frac{\log p}{\log p'} = .434 f \theta$$

from which the value of p' may be evaluated in terms of p and substituted in the previous formula.

Expanding-Band, or Ring, Clutch. The expanding-band clutch finds favor among few. Like the contracting band, which is very similar to the band form of brake, the expanding band is much like the expanding type of brake, with the exception that the clutch is used to form the connection between two rotating parts. Viewed from the standpoint of pure engineering, the expanding band is little different from the cone type of clutch, granting that the angularity of the operating cam is the same as that of the cone.

Much depends upon how the band is expanded, the methods differing widely in practice. This is usually accomplished by means of screws, which may be either right-handed, or left-handed, or both. In one expanding clutch, the screws are single and right-handed. This superinduces a gain in the power required to clutch by the amount of

$$A, \text{ gain in power} = \frac{2\pi l}{s}$$

in which l is the length of the lever in inches, and s the pitch of the screw in inches. If the screw is made double, i.e., one-half threaded right-hand and the other half threaded left-hand, then the expression should be halved. This latter case being more usual, it will be of interest to resolve the gain into the original formula for power, i.e.,

$$P = \frac{fFRxl}{63{,}000s}$$

Another form is expanded by a double-threaded screw operated by a lever. This, in turn, is moved by a pair of sliding collars on the main clutch shaft, the clutch foot pedal moving these forward.

Disk Clutch. With its advent in 1904, the multiple-disk clutch has steadily grown in popularity until today it is looked upon as the

most satisfactory solution of the difficult clutch problem. Designers who have once adopted it, seldom, if ever, go back to another form, while of the new cars coming out from time to time nearly three-fourths are equipped with some form of disk clutch.

Popularity Compared with Other Forms. Statistics for 1914 show that the disk form of clutch was easily the most popular type, and further comparisons with the previous year, and with the apparent tendencies for 1915, show that it is gaining more rapidly than any other type. Of 230 different chassis for 1914, 119 were equipped with

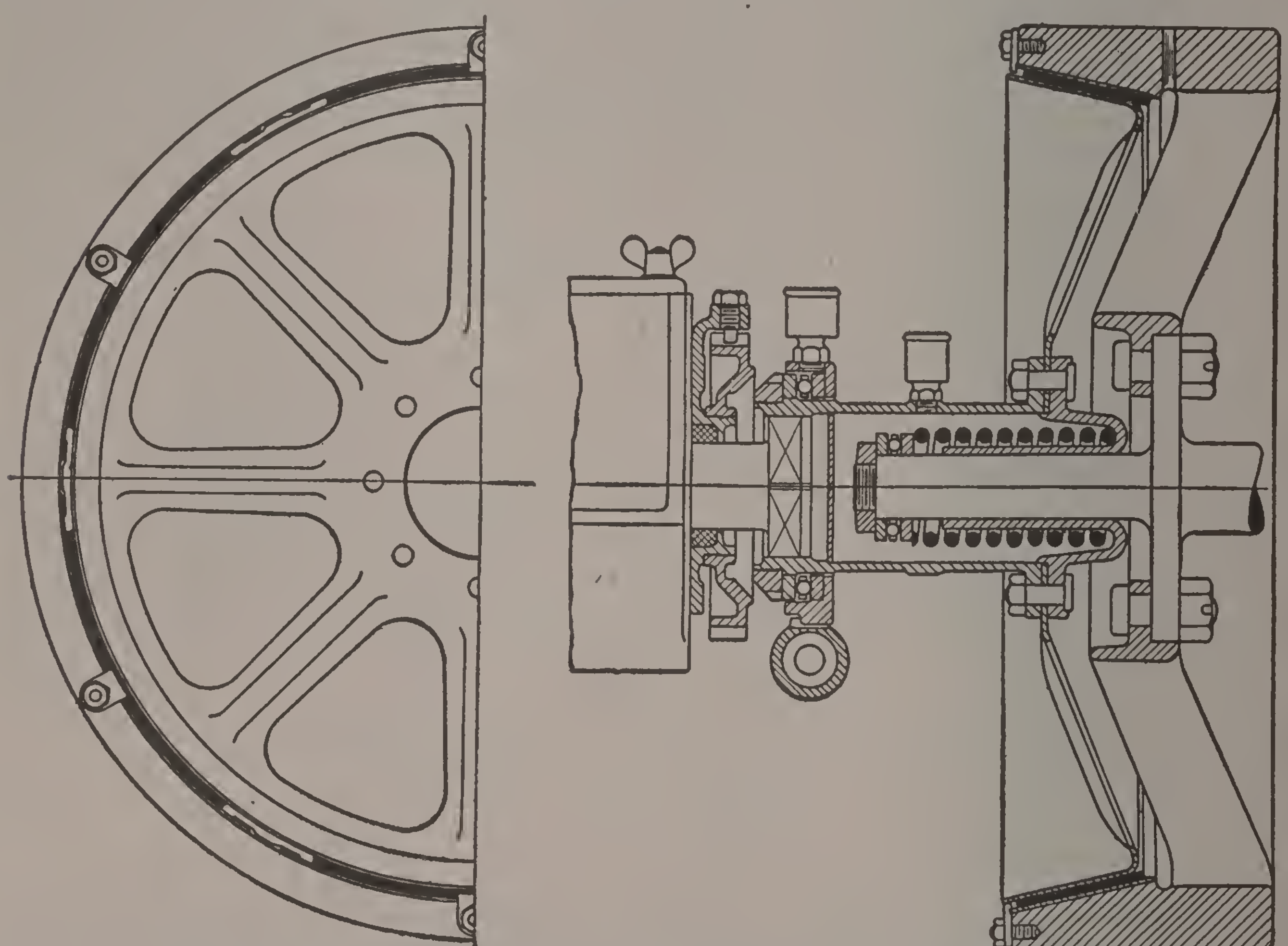

Fig. 50. Cone Clutch for the 18-24 Horsepower Austin (English) Car

disk clutches, 97 with the cone, 9 with a contracting-band type, and but 5 with an expanding-band form. As the majority of the newer models have adopted this form also, while several of the others have changed, the relative figures for 1916 are estimated at about 94 disk, 81 cone, no contracting band, no expanding band, and 1 electric. This would give the first-named approximately 54 per cent of the total.

Two Forms of Same Make. This brings to mind the relative advantages of the two leaders, the cone and the disk. This is presented in a very striking manner in Figs. 50 and 51, which show the cone and disk clutches used interchangeably by the Austin Motor

Company, Birmingham, England, in the 18-24-horsepower chassis. Note in these two that the cone requires a considerably greater length, for in that form it is necessary to make the flywheel with a sloping series of spokes in order to throw the cone farther forward, and thus make room for the greater length of spring. Note that the larger diameter of the cone and its inevitable flywheel action has resulted in the removal of considerable metal from the inside rim of the flywheel. Furthermore, on the disk form, note how the space between the compact disks and the rim of the flywheel is used as a

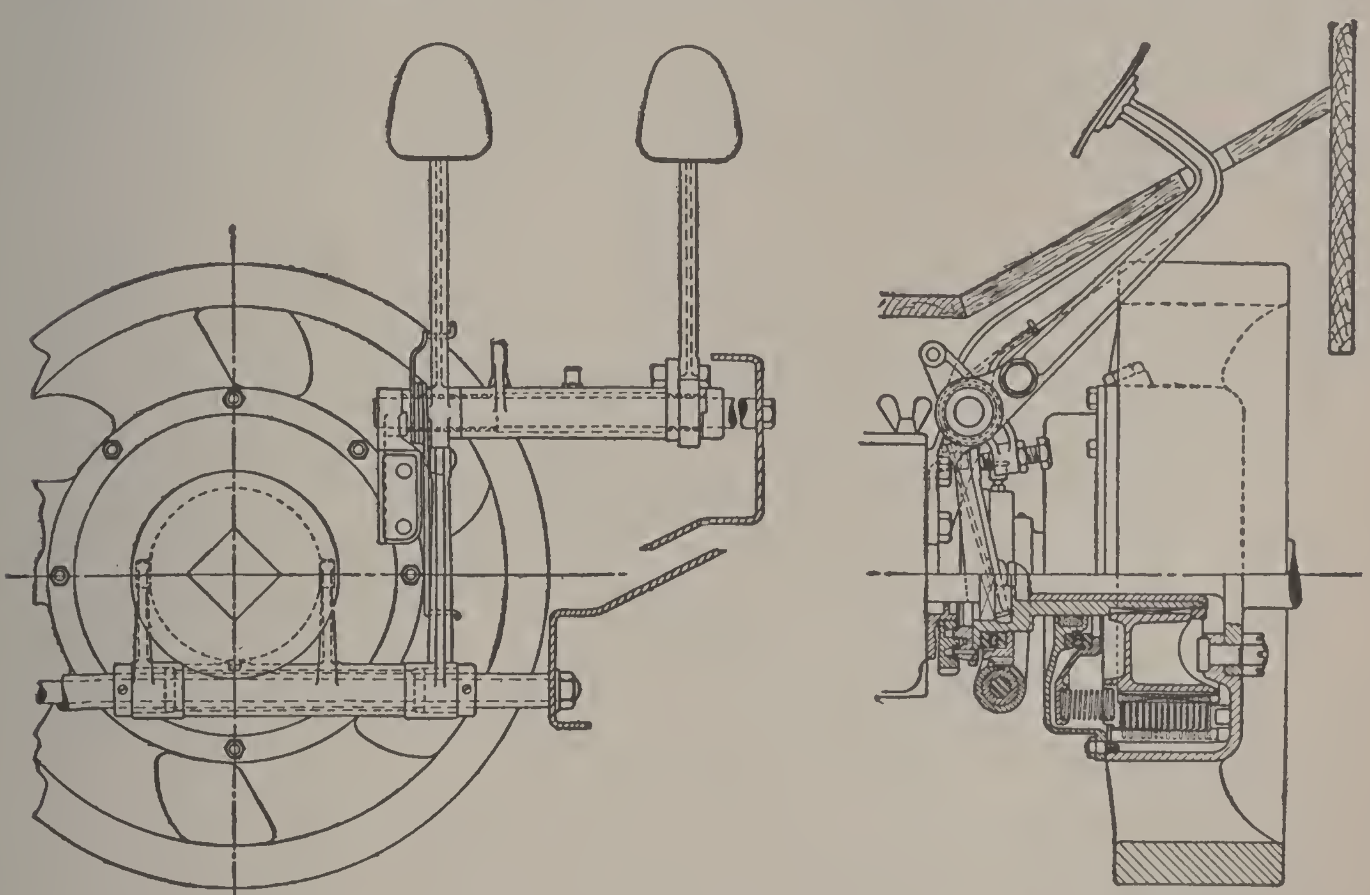

Fig. 51. Disk Clutch for the 18-24 Austin for Comparison with Fig. 139.

fan, six blades being set in here in place of spokes, these assisting in cooling the water.

While the cone is apparently more simple, it will be noted on closer inspection that the pedal and other operating mechanisms are all shown in the disk form, while none are shown in the cone type. If the two drawings were on a par, they would show little or no difference in this respect beyond the fact that the disks and their springs make some 40 or 50 parts, while the cone and its spring parts do not total much more than half a dozen.

On this cone form, special attention is directed to the method of applying the clutch lining in six sections, with a single bolt and clip above each. It is said that any one of these lining sections can be

removed in a couple of minutes without touching any other parts. In both instances, note the braking surface provided to stop spinning when the clutch is removed. In the case of the cone, this is a single conical surface at the left of the figure, while on the disk it consists of a pair of wedge-shaped projections which enter a pair of similarly shaped grooves, this giving actually four braking surfaces. In the latter, too, attention is called to the simple adjusting means, a single large set screw, with a locknut, being so placed that when the throw of the pedal is not just right for engaging or disengaging, a turn of the screw allows of more or less movement, according to the needs.

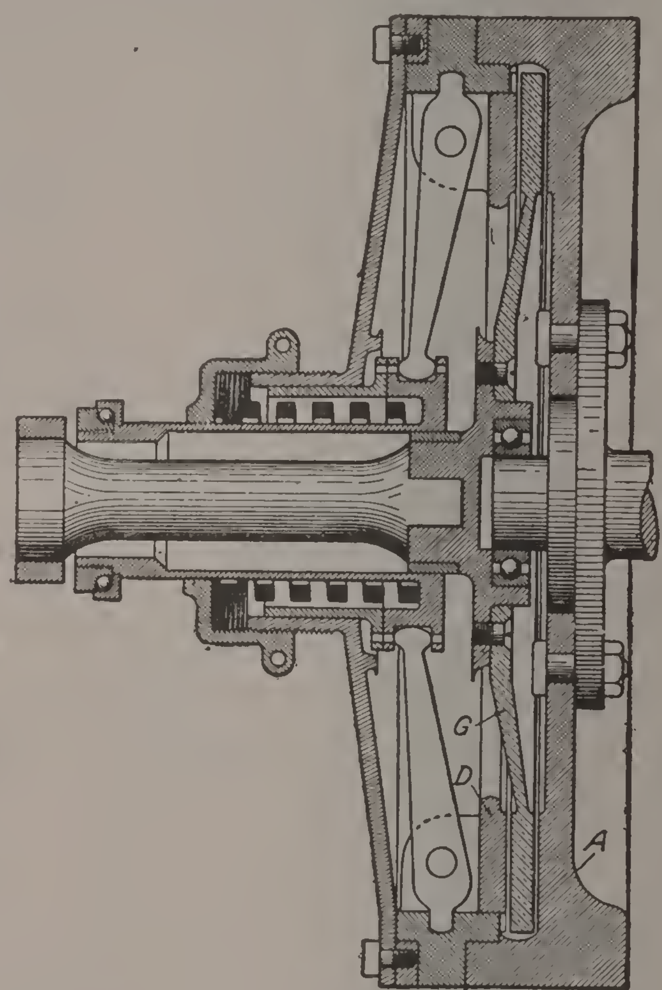

Fig. 52. Austin Clutch with Single Disk
Austin Automobile Company, Grand Rapids, Michigan

Simple Type. These differ in number and shape of disks, method of clutching, material, and lubrication; but in principle all are alike. This, briefly stated, is that *flat surfaces properly pressed together will transmit more power with less trouble than any other form.* By multiplying the number of surfaces and making them infinitely thin, the power transmitted may be increased indefinitely. That this is not idle fancy is shown by a number of very successful installations of 1000 horsepower and over in marine service, and certainly no such power is required for an automobile.

The minimum number of plates in use is said to be three, but very often the construction of a three-plate clutch is such that one or two surfaces of other parts are utilized, making it a two- or even one-plate clutch in reality. Thus, in the Austin clutch, shown in Fig. 52, made by the Austin Automobile Company, Grand Rapids, Michigan, a copper disk G of some thickness is clamped by spring pressure between the flywheel A and a floating ring D. In reality, the copper disk transmits all the power, the flywheel being a necessity, and the

floating disk only an accessory before the fact. It would, therefore, not be wrong to call this a *one-plate* clutch.

Multiple-Disk Clutches. The modern tendency in disk clutches, however, is away from those of few plates requiring a very high spring pressure—since the friction area is necessarily limited—toward the multiple-disk variety, in which a very large area is obtained. This allows of a very light spring pressure, and consequently is easier to engage and disengage and, for this reason, it is becoming more popular with owners and drivers than the variety requiring the extra-heavy effort. The construction of the three-plate disk clutch does not differ radically from one maker to another. Three fingers are used to clutch and declutch generally, the amount of movement being adjustable. A single spring of large diameter

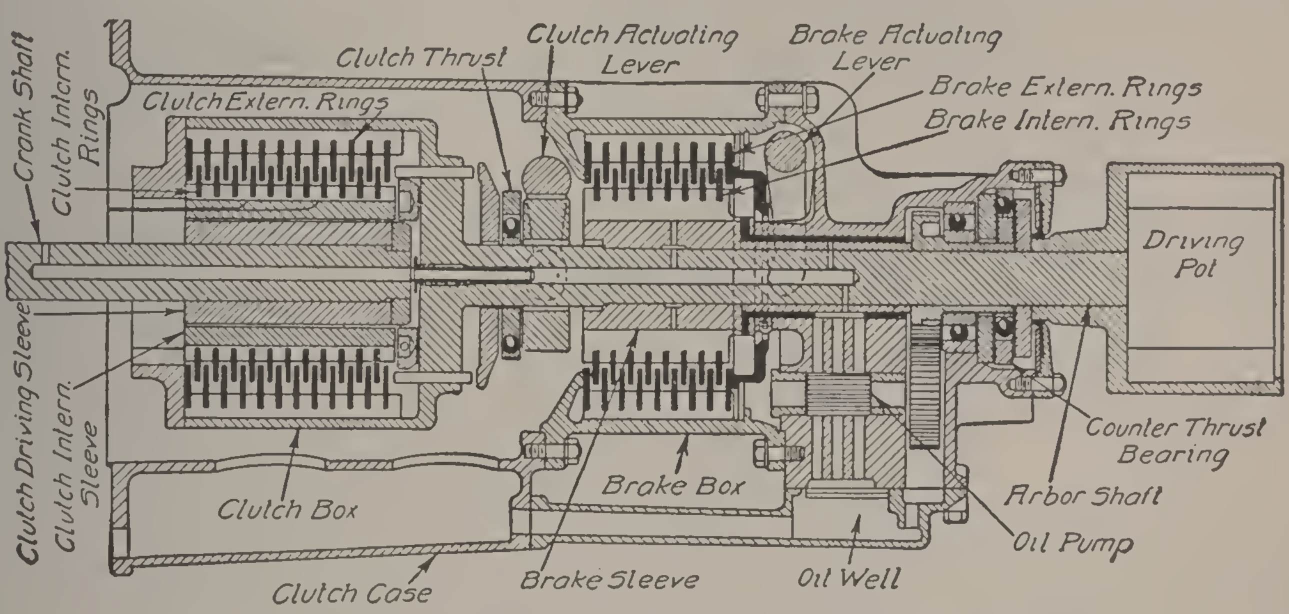

Fig. 53. Lanchester (English) Disk Clutch and Disk Brake

and large-sized wire is generally used, and sheet steel is used for one-half the clutch plates. Between the *three-plate* and *multiple-disk* are many gradations.

In the true multiple-plate clutch, there are three general varieties met with in practice: the metal-to-metal with straight faces; the metal-to-metal with angular or other shaped faces, designed to increase the holding power; and the straight-face kind in which metal does not contact with metal, one member being either lined with a removable lining or else fitted with cork inserts.

Disk Clutch and Disk Brake. A most unusual combination of clutch and brake is to be found in the English Lanchester cars. In this, as shown in Fig. 53, the multiple-disk clutch is placed at the forward end of the shaft, and consists of 12 external or driven

disks and 11 internal or driving disks. These are comparatively small in size, and are stamped from flat pieces of steel, the external members having a square shape, with a projecting key at each corner, while the round internal members have six projecting keys.

The latter fit onto a splined shaft on which the keys correspond with the spaces inside the driving disks, while the keyways correspond with the projections or keys in the disks. In this way, all the driving disks are driven by the shaft, carried around with it at all times. Between each pair of these is an external or driven disk. These have their keys fitted into four slots in the corners of a square hole in a driven sleeve or casing.

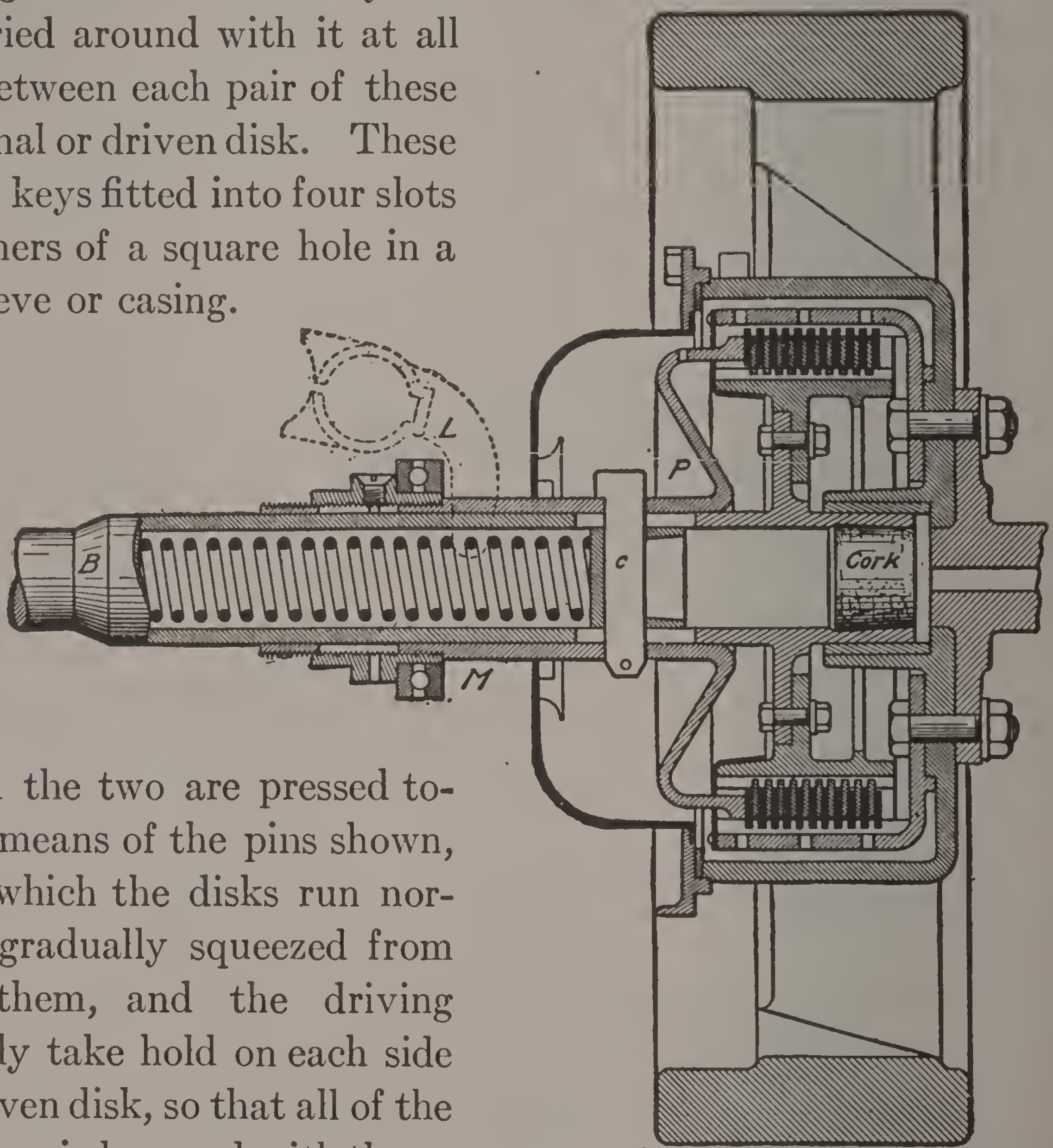

Fig. 143. Panhard Disk Clutch with Spring Fully Enclosed

When the two are pressed together by means of the pins shown, the oil in which the disks run normally is gradually squeezed from between them, and the driving disks slowly take hold on each side of each driven disk, so that all of the latter are carried around with them. These must take the casing with them, because they are keyed into it, consequently when the oil is entirely squeezed out and the disks grip, the whole clutch revolves as a unit.

The brake, which is shown directly back of the clutch, but which is operated by a separate pedal, is constructed in exactly the same manner and is similarly operated. There is this exception, however, in that the external rings—the driven members in the case of the clutch—are in this case entirely stationary, being held by keys on the casing,

which cannot turn. That being the case, as the pressure is applied through the medium of the foot pedal, and as the oil is squeezed from between the nine external and eight internal plates, the power is gradually absorbed, and the car slows down or stops according to the amount of force applied and other conditions. The two sets of plates are identical, and except for their number, are interchangeable. As has been stated, all these run in oil, and to make sure of a copious and continuous circulation, an oil pump is placed in the bottom of the rear end of the casing, being driven off the main shaft. To facilitate its use, the bottom of the case forms an oil well.

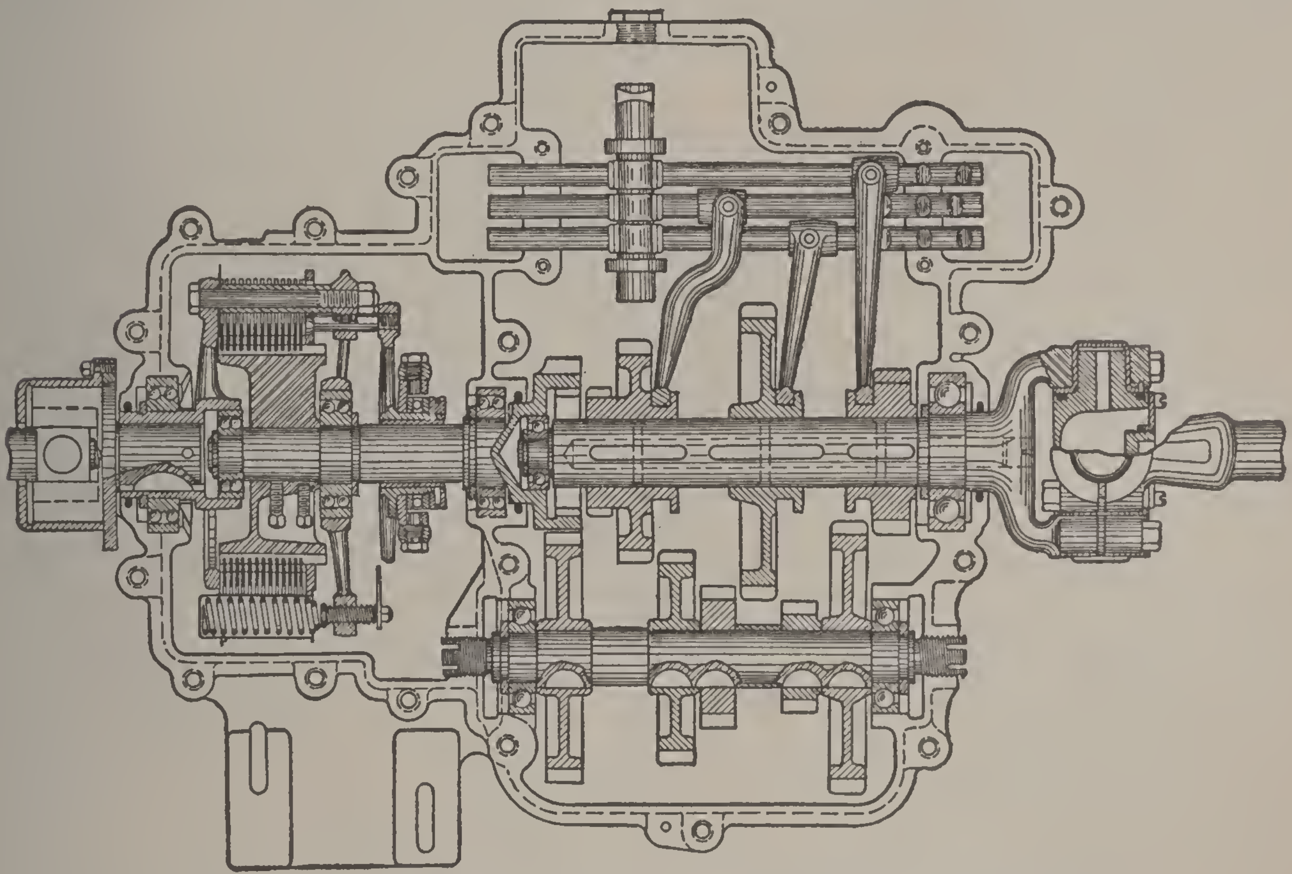

Fig. 55. Multiple-Disk Clutch and Transmission of Winton Cars
Courtesy of Winton Motor Car Company, Cleveland, Ohio

Metal-to-Metal, Dry-Disk Type. This method has the additional advantage that the central part within which the clutch is housed is very small in diameter, so that the portion of the flywheel between the rim and the clutch housing may be made in the form of fan spokes, thus converting it into a fan and serving to cool the motor better.

Many designs follow this method, one prominent example being shown in Fig. 54. This is of the all-metal type with plane faces, used by the French constructors, Panhard and Levassor.

In this type, the spring presses the member P forward, jamming one-half the disks against the other half, this jamming action transmitting the power. To throw out the clutch, the lever L moves

backward and pulls with it the casing M, this being connected to the member P draws the latter out and away from the disks. The natural spring of the latter then asserts itself, and they free themselves.

As the various examples of disk clutch shown would indicate, the designer has had his choice between a few large disks and a large number of small ones. If he chose the former, the clutch could be housed within the flywheel, but this makes it inaccessible, although saving length. If he chose the latter, the clutch could not be kept within the flywheel length, a separate clutch housing being a necessity, but the clutch could be made accessible and flywheel fan blades could be used.

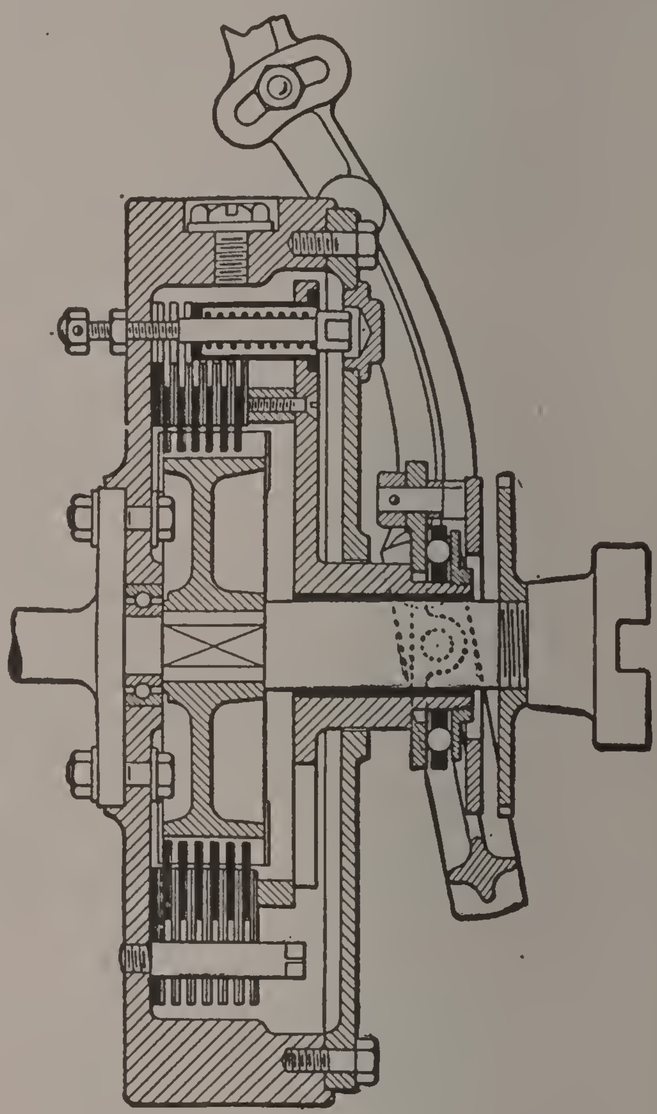

Fig. 56. Argyll (Scotch) Disk Clutch

Another example of the plain metal-to-metal disk clutch is shown in Fig. 55. In this case also the clutch is not housed in the flywheel, as in most of the preceding examples of this form of clutch, but in the forward end of the transmission case. That is, instead of motor and clutch forming a unit, the latter is a unit with the transmission. It is claimed that this position makes it more accessible, since it brings the clutch directly under the floor boards of the driver's compartment, and that better lubrication is another result. The latter is effected through communication with the gear part of the case, which is always filled with lubricant.

In the figure it will be noted that there are 13 driven disks, with keyways, which hold them to the driven drum. Note that the latter is held to its shaft by means of a pair of large set screws. The clutching springs are of small diameter and size, spaced equally around the periphery of the disks, each being enclosed in a small and thin metal casing. Attention is called also to the universal joint shown, this

forming the rear end of the driving connection with the flywheel, which will be referred to later. These disks are perfectly flat, stamped out of sheet steel with the proper keyways for internal or external holdings.

Differing from the foregoing is the clutch used on the Scotch Argyll cars, Fig. 56. In this the disks have been made larger in diameter and smaller in number. Moreover, no use of the flywheel as a fan has been attempted.

Use of Facings. The more modern disk clutch has two sets of sheet metal disks, one of these being faced on one side or both with a special material. Without a single exception, all the disk clutches shown have had plain disks against plain disks. This makes a simple and fairly inexpensive construction, but as has been found out recently, one that is not very efficient. Thus, the most recent tests have shown that metal against metal gives a coefficient of friction of but .15, which is reduced to .07 when the surfaces become oily or greasy. With one of these contacting faces lined with leather, this rises to .23 when dry, and .15 when oiled. Again if fiber is used for the facing, the coefficient becomes, respectively, .27 and .10, while with cork or cork and leather, it becomes, respectively, .35 and .32. Here then is a very apparent reason for (1) facing the clutch disks, and (2) running them dry.

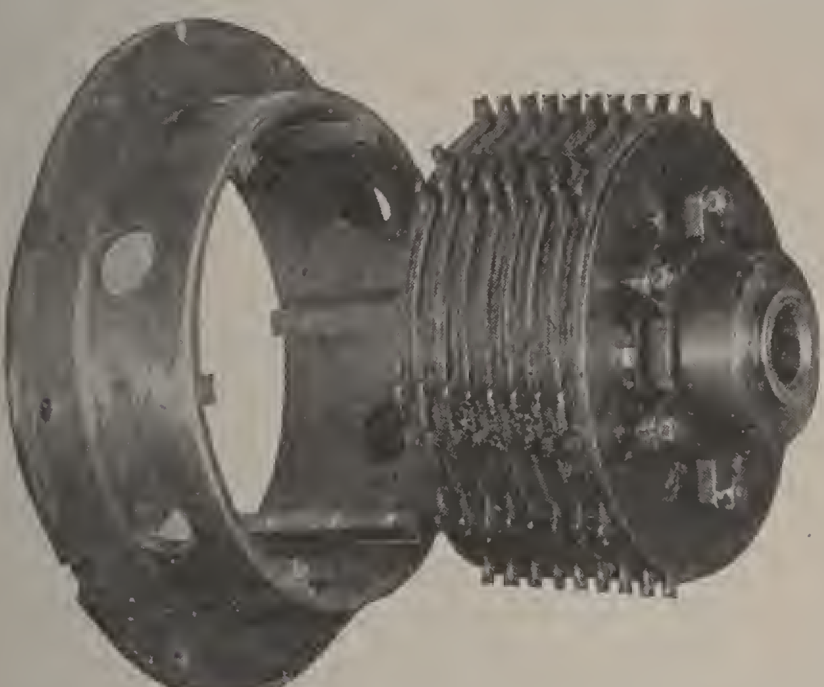

Fig. 57. Multiple-Disk Clutch Used on Cadillac Cars
Courtesy of Cadillac Motor Car Company, Detroit, Michigan

By going over these figures, it will be noted that disks with almost any form of facing will show an increase in efficiency over the same disks without facing, varying from 60 up to almost 300 per cent. Again, any form of disk clutch, faced or otherwise, will show a much higher coefficient dry than oiled, and thus, a greater efficiency. These two facts point out the obvious reasons for the modern tendency toward the multiple-disk clutch, faced and running dry.

To present an example of the faced type, Fig. 57 shows the multiple-disk clutch of the eight-cylinder V-type Cadillac. In this, the eight driving disks can be seen, with the facing on each side of each one. This facing is of wire-mesh asbestos, and between each pair of disks comes a plain driven disk, so that it has a facing of the asbestos against each side of the metal which it grips. The six keys which hold and drive the outer disks can be seen on the inside of its housing, while the slots into which these project can be seen on the periphery of the disks. By examining the group closely, the driven plain disks can be seen between each pair of the drivers. Fig. 58 shows the pedals and the exterior of the clutch case, where it bolts up to the engine. This indicates how a unit power plant simplifies the control group, and eliminates parts.

Fig. 58. Housing and Foot Pedals on the Cadillac Car

Floating Disks, a Novelty. The clutch on the Locomobile cars, shown in section in Fig. 59, is very much like the Cadillac just shown, except for this novel feature, that the fabric facings are not attached either to the driving or to the driven disks, but float between them. This fabric, usually a woven asbestos material with a central core of interwoven metal wires, instead of being attached to both sides of every other disk or to one side of every disk, is not attached at all. The rings for the fabric disks are made up in the form of annular rings, have the same inner diameter as the inside of the driving disks, and the same outside size as the driven disks; consequently assembling one of these clutches is simply a question of piling first a driven disk, then a fabric, then a driving disk, and so on.

Because of the fact that the fabric rings are not united to either of the metal disks, they free themselves with remarkable rapidity so that either on engagement or on declutching the action is very quick.

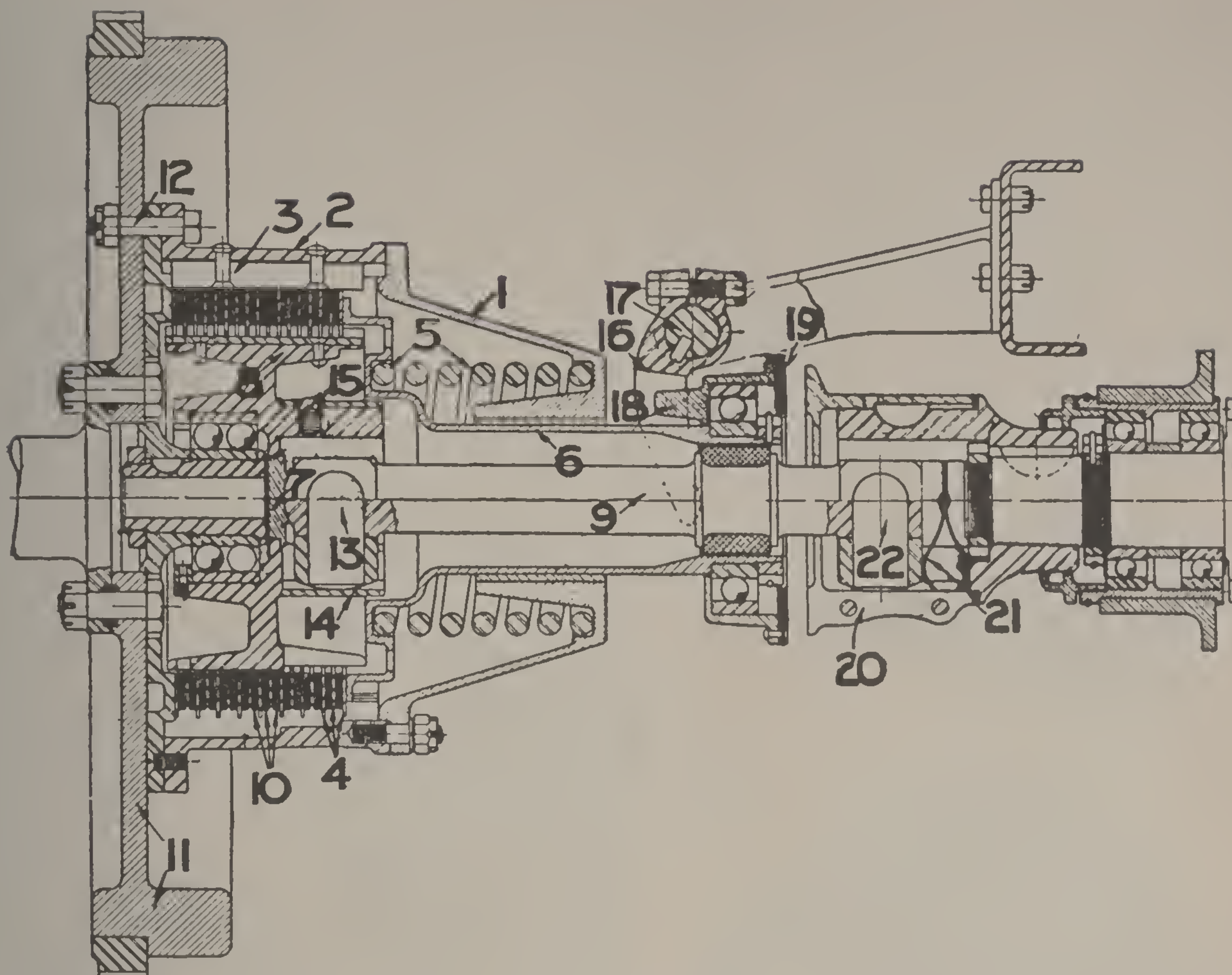

Fig. 59. Floating Dry Disk Clutch Used on Locomobile Cars

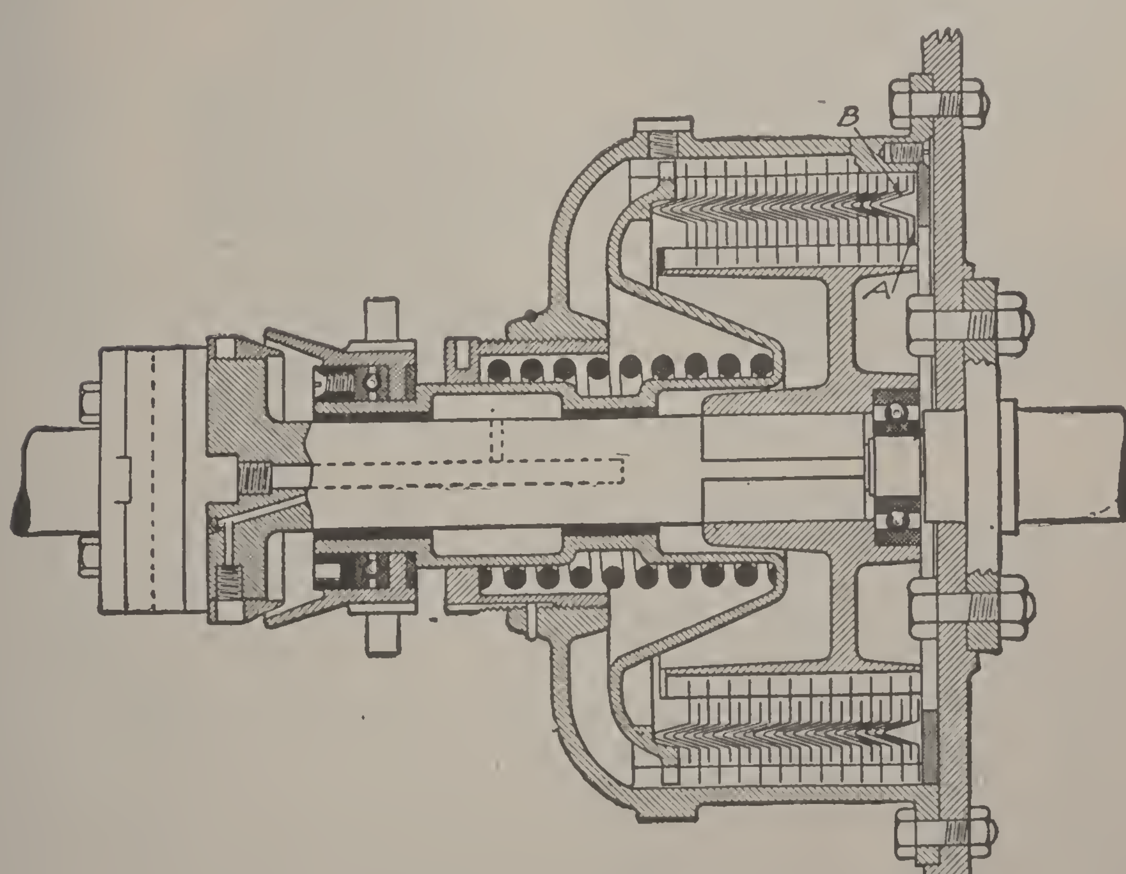

Fig. 60. Hele-Shaw Disk Clutch Showing Cone Surfaces

Greater Power Transmitted by Surfaces Not Plane. To increase the power transmitted by a clutch of given size, either the number of plates must be increased or the form of the surface changed. The latter method was followed on the clutch of the French car, *Ours*. The disks of this unusual clutch had a perfectly flat outer portion, and a conical inner portion, only the latter taking part in the transmission of power. In this disk form, then, we have the advantage of the disk economy of space, together with the advantages of the cone clutch, and the additive gain of running in a bath of oil.

Fig. 61.

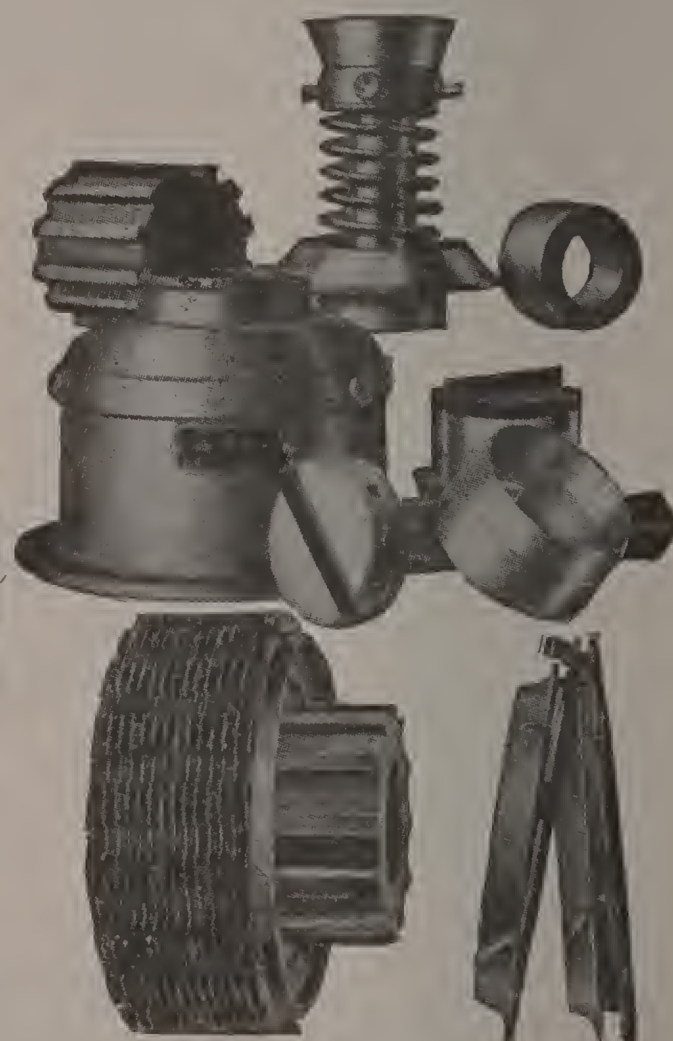

Fig. 62.

Disassembled Hele-Shaw Clutch

Another form utilizing this principle, and one that is more widely used, is that known as the *Hele-Shaw*, so named from its inventor, the famous English scientist, Dr. H. S. Hele-Shaw. This is essentially a flat disk, as shown at A, Fig. 60, with a ridge B at about the middle of the friction surface, this ridge consisting of a portion of the surface, which has been obtruded during the stamping process in such a way as to leave the surface of the ridge in the form of an angle of small size. The angle used is 35 degrees, and this value has been determined upon experimentally as the best. Fig. 60 shows a

cross section through an assembled clutch, which reveals the clutch angle very plainly. In use, the ridges nest one on top of the other; and in the extreme act of clutching, not only the flat surfaces but both sides of the ridge are in contact with the next plate. Thus, not only is the surface for a given diameter increased, but the wedge shape is also taken advantage of. Smaller views of the single disks and of the complete clutch, disassembled to make plain its simplicity, are shown in Fig. 61 and Fig. 62.

A brief mention of the method pursued in the design of flat disk clutches will not be out of place. Consider the disk to be used as an annular ring having an internal radius r_1, and external radius r_2. If f is the coefficient of friction, n the number of disks, and p the specific pressure normal to the friction surfaces as distinguished from the spring pressure, then by certain theoretical considerations involving integral calculus, it is found that the moment M of the clutch around the center will be as follows:

$$M, \text{total} = \frac{pf\pi(n-1)}{18}(r_2^3 - r_1^3) \text{ in foot-pounds}$$

In use, the factor p is found first, by figuring the area of the whole surface and dividing the spring pressure by it

thus $$\text{area} = \pi(r_2^2 - r_1^2)$$
and the specific pressure is

$$p = \frac{\text{spring pressure}}{(r_2^2 - r_1^2)}$$

Knowing the material, the coefficient of friction is known, and therefore everything is known but the number of plates and their size. By trial the size may be selected, from which the number is easily figured, using the above formulas. Care should be taken in their use to add 1 when the number of plates comes out with a decimal or fractional quantity. In the use of a formula like the preceding one, it is always assumed that the power is known at some specific speed. This being the case, the total torque, which is divided by the total moment to find the number of the plates to use, is

$$T, \text{total} = \frac{hp \times 33{,}000}{2\pi \times \text{speed}}$$

Hydraulic Clutches. All the methods of engaging and disengaging the engine at will, as discussed before, have been of a

mechanical nature. The hydraulic clutch, on the other hand, partakes more of the fluid nature, although semi-mechanical, i.e., operated by mechanical means. Ordinarily it is in the nature of a pump with a by-pass, the pump working at ordinary speeds to force the heavy liquid, usually glycerine, through the by-pass. To clutch up tightly, however, the by-pass is closed and, the liquid being unable to circulate while the pump continues to operate, the whole device is rotated as a unit. In this case it operates just as any other clutch, but, due to the sluggish action of the fluid, it is slower to respond. Then, too, there is always present the grave question of leakage, since the smallest leak puts the clutch entirely out of use. These disadvantages, together with the necessary complications, have retarded the development of the hydraulic form so that there are few of them in use today. In the clutch shown in Fig. 63, a spider

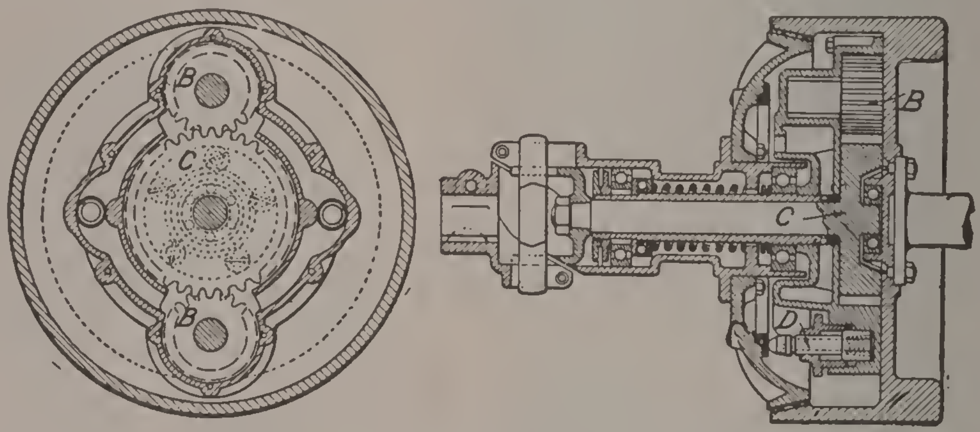

Fig. 63. Stilson Hydraulic Clutch

is fast to the engine shaft and carries two spur gears *B B*. These are constantly in mesh with *C*, which is fast to the driven shaft. The space surrounding these gears is filled with oil, which is pumped around by the rotation of the gears. Several valves, one of which is shown at *D*, allow the oil to circulate freely. Under these circumstances, the pinions on the crankshaft run around the gear on the driven shaft and transmit no motion to the latter. These valves are held open by springs, but by the operation of the foot pedal, a cone is brought forward which presses against the heads of the valves, closing them. Partly closed, the pinions drive the gear slowly, because of the resistance which the liquid offers, and when wholly closed, the transmission shaft is driven at full speed with little loss, since the fluid is not very compressible. This clutch was formerly made by the Stilson Motor Car Company, Pittsfield, Massachusetts, which firm has since gone out of business.

Another clutch designed with the same idea, but worked out in a far different manner, is that of the North Chicago Machine Company, North Chicago, Illinois, and shown in Fig. 64. This clutch is more complicated and has many more parts than the Stilson clutch, but has the advantage of having seen more severe trials and more actual service. It acts as does the Stilson, oil normally passing through passages when the clutch is out, but when prevented from passing, the whole mechanism turns as a unit. The prevention of the liquid passing is accomplished by an eccentric device not very different from a vane type of water pump, the method of throwing it into and out of engagement being very complicated. Fig. 64 shows all the parts, and a study of it will reveal the complete action.

Fig. 64. Pambla Hydraulic Clutch
Courtesy of North Chicago Machine Works, North Chicago

Magnetic Clutch. All the foregoing clutches present in one form or another very complicated devices for freeing the transmission shaft from the engine shaft, but the magnetic clutch is a device which has simplicity for its foremost argument. The magnetic clutch, consists primarily of three parts: the field, usually in the form of a ring; the armature always of ring shape; and the oil casing shaped to accommodate the other parts, its function being that of a cover, simply. The armature is a simple cast-iron plate of rectangular section, adapted to be drawn into engagement with the field, when the latter is energized.

The field, on the other hand, is made up of the back plate, the inner and outer field rings, the magnetizing coil and the contact rings. In operation, the accelerator is energized by closing the electrical circuit, which sends a current through the field. This magnetism attracts the armature, which then moves laterally, clos-

ing the very small gap between the two. The oil in which the whole clutch works prevents it from taking hold suddenly, or gripping, but as this oil film on the two surfaces is gradually squeezed out, the clutch as gradually takes hold.

New Electric Generating Clutch. So great has been the interest in the various electrical mechanisms in the automobile, and so quickly has the public taken up with all these that this has stimulated an entirely new invention, called, by its maker, the Vesta Accumulator Company, Chicago, a *centrifugal electric-generating clutch.* This name gives a little clue to its action, which is a combination of the usual friction clutch and that of the electric-magnetic drag between armature and fields of any electric machine.

In addition to its clutching feature, its ability to drive when partially clutched makes it, in effect, a transmission, so that it is designed to replace the usual clutch, gearset, flywheel, electric generator and starting motor. It is composed of two parts: an armature, which becomes the flywheel; and a field mounted on the propeller shaft. The former carries an internal commutator, and the latter, brush holders which hold brushes against the commutator. These are mounted so that the centrifugal force of rotation increases the force with which they press against the commutator. Thus there is a variation from practically no contact up to the maximum, at which point the centrifugal force is so great that field and armature revolve as a solid unit.

An automobile built in France—the Ampere—uses this construction exclusively, the master clutch being dispensed with in favor of an individual clutch transmission, the clutches being magnetically operated as just described. In addition, the differential is dispensed with, and in its place is used a pair of magnetic clutches, one for each wheel. The differential action is obtained on curves by decreasing the current to the clutch on the inner wheel up to a certain point, at which it is cut off entirely. This gradual reduction and cutting off of the current is accomplished automatically by the movement of the steering wheel.

Clutch Operation. Practically all modern clutches are operated by means of a special pedal, moved by the left foot. This is connected by means of rods and levers to the internal member, which compresses the clutch spring or springs, thus allowing the clutch

members to separate. In this way the clutch is thrown out. To throw it back in, the foot pressure is removed from the pedal, the springs again exerting pressure and forcing the parts together, thus allowing them to take hold. There was a time when a considerable number of cars had the clutch so constructed that the pedal held it in and the springs threw it out, just the reverse of the present plan. This, however, is no longer used, as it necessitated maintaining a constant pressure on the pedal while driving, and after a long ride this became very fatiguing.

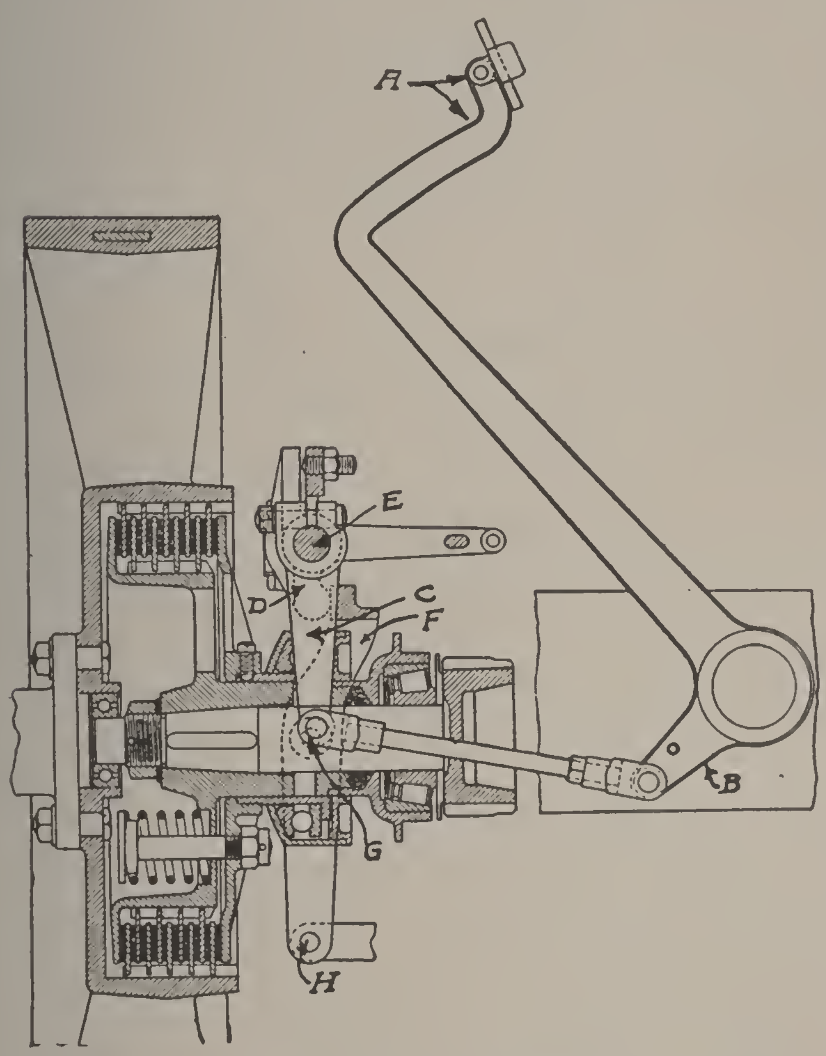

Fig. 65. Multiplying Lever of Dorris Clutch to Make Pedal Pressure Light
Courtesy of Dorris Motor Car Company, St. Louis, Missouri

Gradual Clutch Release. The Dorris clutch made by the Dorris Motor Car Company, St. Louis, Missouri, Fig. 65, is a new arrangement of the clutch pedal, and its operation is such that the clutch is released or thrown out with very light pressure on the pedal. Pressure on the pedal A is transmitted by the shorter lever arm B, thus greatly increasing the leverage. This pressure is transmitted to lever C and through it to lever D, these two being hung on the frame across member E. As C is much longer than D, there is another multiplying action here. This does not act directly upon the clutch, but upon the upper end of the clutch shifter F, which is attached to the clutch at G and pivoted at its lower end H—here again in a multiplying action. The net result of these three multiplications is a combination which will release the strongest and stiffest clutch with a very slight pressure of the foot.

Clutch Lubrication. As has been previously pointed out, some clutches run in oil, while others run dry. The former type must be

kept filled with lubricant at all times, the general plan in such a case being to provide a lead from the engine oiler when the clutch case is separated from the engine case, or a connecting means when the two are in one case. In addition to the actual clutching members, there is practically always a sliding member, which must have lubricant of some form, while the thrust bearings to take the thrust of the clutch springs must be cared for. Generally, these two cases are cared for by a pair of grease cups, these being visible in Figs. 44 and 50. The operating rods are lubricated usually by means of small oil holes, either drilled directly into the part or covered with a small oil cup. In those cases in which the clutch runs in oil, it will be noted that a filling plug is provided, by means of which additional lubricant can be poured into the casing. For this, refer to Figs. 47, 51, 56, and 60.

Clutch Bearings. The need for bearings in a clutch depends somewhat upon its nature and location, but regardless of these a thrust bearing is needed for the clutch spring. To explain this briefly, it is known that action and reaction are equal, and opposite in direction. For this reason, when a clutch spring presses the disks or parts together with a force of, say, 100 pounds, there is exerted in the opposite direction this same force of 100 pounds. In order to have something for this to work against, a bearing is used, and since it takes up this spring thrust, it is called a thrust bearing. Not all bearings are fitted to take thrust, the majority of them being designed for radial loads only. For this reason a special design is needed.

When the clutch is incorporated in the flywheel, there are needed, generally, two additional bearings, one for the end of the crankshaft and another for the transmission or driven shaft. This will be noted in Figs. 42, 51, 52, 59, 60, and 55, although the last-named does not have the clutch combined with the engine, but rather with the transmission. In the majority of cases, it will be found that a means of fastening the end of one shaft has been worked out so as to eliminate one bearing. This accounts for the large number which show but two—the thrust and one other. In looking back over these, it will be noticed also that practically all the bearings are of the plain ball form. This is due in large part to the fact that these take up the least room for the load carried, both in diameter and width, a contributing reason being the fact that in many cases

one of the shafts or parts can be formed to take the place of either the inner or outer ball race.

Clutch Adjustment. In general, adjusting a clutch is not a difficult task, there being but two possible sources of adjustment; the throw or movement of the operating pedal or lever, and the tension of the spring. Generally, an adjustment is provided for each. When the fullest possible throw of the pedal does not disengage the clutch, an adjustment is required to give a greater throw. If the throw is correct, but the clutch takes hold too quickly and vigorously, then the spring pressure can be lessened somewhat to soften down this action. On the other hand, when dropped-in quickly, if it takes hold slowly, more spring pressure is needed, which is obtained by tightening.

Clutch Accessibility. Clutches are made accessible in two ways: by their location on the car, and by the relative ease with which they can be removed. Accessibility as to location is less in the various combinations, such as in the unit power plant, housed within the flywheel, or combined with the transmission. Ease of removal is determined by the number and location of the joints (usually universal) used with the clutch. Sometimes, one on each side makes removal easy, but generally, a single universal makes much work.

CLUTCH TROUBLES AND REMEDIES

The very fact that the clutch is a more or less flexible—or rather, variable—connection between engine and road wheels makes it necessary that it be kept in the best of shape. It is rather surprising to the novice, with his first clutch trouble, to have his motor racing at the highest possible speed, and to find his car barely moving, but to the experienced driver it is humiliating.

Slipping Clutch. Slipping is the most common of clutch troubles. This is brought about in a cone clutch by oil, grease, or other slippery matter on the surface of the clutch, and can often be cured temporarily by throwing sand, dirt, or other matter on the clutch surface, although this is not recommended. Many times, the clutch leather or facing becomes so glazed that it slips without any oil or grease on it. In that case it is desirable to roughen the surface by taking the clutch out, cleaning the surface with kerosene and gasoline, and then roughing up the surface with a file or other similar tool.

In case it is not desired to take the clutch out, or when it is very inaccessible, the clutch surface may be roughened by fastening the clutch pedal in its extreme out position with some kind of a stick, cord, or wire, and then roughing the surface, as far in as it can be reached, with the end of a small saw, preferably of the keyhole type, about as shown in Fig. 66. Before starting this repair, it is well to soak the leather with neatsfoot oil, pouring this in the night before and allowing the leather to soak up as much of it as it will. This softens the leather and makes the roughening task lighter.

Many drivers make the mistake of driving with the foot constantly on the clutch pedal. This wears the leather surface and helps it to glaze quickly. The constant rubbing, due to slipping it frequently, also makes the leather hard and dry.

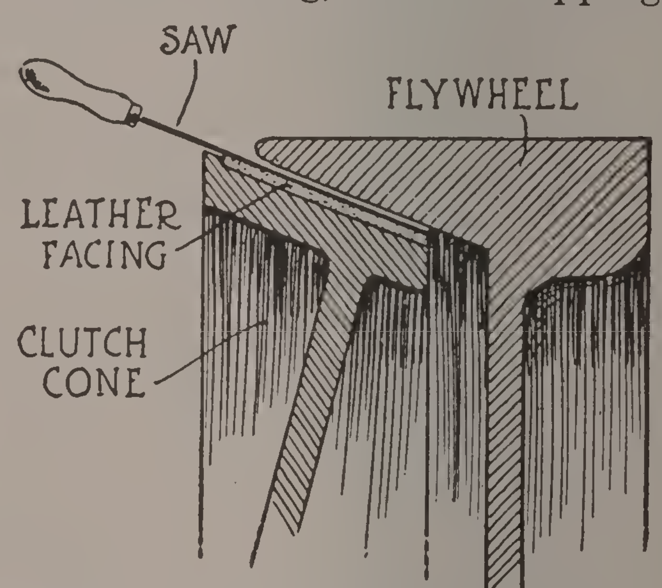

Fig. 66. Method of Roughing-Up Clutch Leather with Saw

When a metal to metal, oiled clutch slips, the trouble usually is in the clutch spring which is too weak to hold the plates together. To remedy slipping with this type then, it is necessary to tighten up on the clutch spring adjustment.

Clutch troubles are not always so obvious. In one instance, the clutch slipped on a new car. In the shop, the clutch spider seemed perfect, also the spring, and properly adjusted, but to make sure, a new clutch was put in. Still the clutch slipped. To test it out still further, the linkage was disconnected right at the clutch and then it held perfectly, showing that the trouble was in the linkage. On examination one bushing was found to be such a tight fit that it would not allow the pedal to move freely enough to release fully. When this was relieved a little, the clutch acted all right.

Handling Clutch Springs. Clutch springs, like valve springs, mentioned previously, are mean to handle and compress, the best way being to compress and hold them that way until needed. For this purpose, a rig similar to that described for valve springs should be made but of stiffer, stronger stock. A very good one can be made from two round plates, one small, and the other of larger

diameter with a pair of **L**-shaped bolts through it. The spring is placed between the two with the ends of the **L**'s looped over the smaller plate, and then, by tightening the nuts on the bolts, the spring is gradually compressed.

Fierce Clutch. A "fierce" clutch is one that does not take hold gradually, but grabs the moment the clutch pedal is released. In a metal disk clutch, this is caused by roughened plate surfaces and insufficient lubricant, so that instead of the plates twisting gradually across one another as the lubricant is squeezed out from between them, they catch at once and the car starts with a jerk. On a cone clutch, this fierceness is produced by too strong a spring, too large a clutching surface in combination with a very strong spring, or a hard or burned clutch surface, or both.

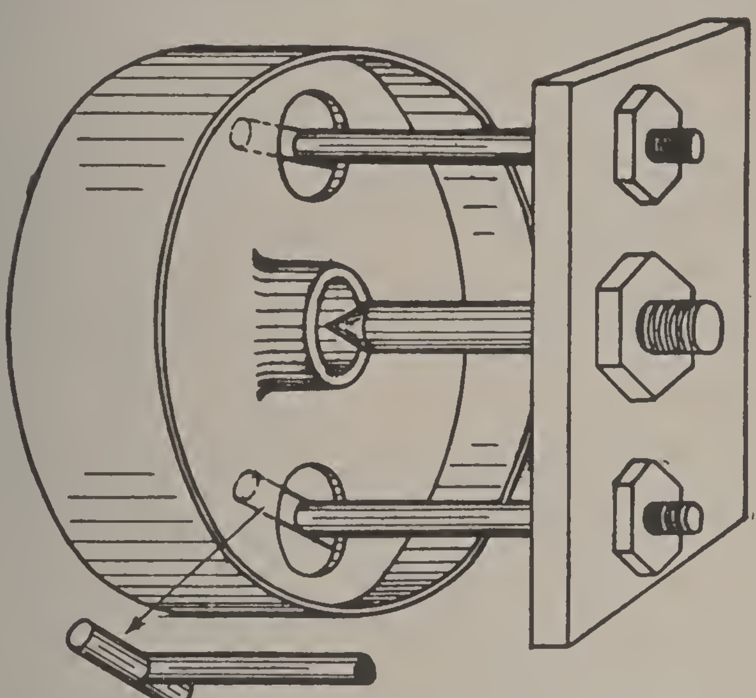

Fig. 67. Simple Rigging for Removing Ford Clutch Disk

Ford Clutch Troubles. There are now so many Fords in use that the average repair man feels justified in making special apparatus or tools to save time or work in Ford repairs. For one thing, the clutch disk drum frequently needs removal and this is a difficult job. By means of a simple rigging, however, consisting of a plate and a few bolts, it can be taken off in a few moments and with little trouble. It will be noted from Fig. 67 that the rigging is but a modified form of wheel puller. It consists of a $\frac{1}{4}$-inch plate of steel with three holes drilled in it for three bolts. The two outside ones have **T**-head ends and have to be specially made, and made carefully, as this **T**-head must slip through either one of the oval holes in the web of the drum. When this is done, it is straightened up so as to stand at right angles to the drum and is thus in a position to press firmly against the drum from the inside. There are nuts on the center bolt on both sides of the plate, the drawing showing only that on the outer end. When the **T**-bolts are in place, the center bolt, which is slightly pointed and preferably hardened on

the end, is screwed down so as to come into contact with the end of the clutch shaft. After tightening this, the T-head bolts are tightened until they pull the drum off the shaft.

Clutch Spinning. A trouble which is bothersome but not dangerous is clutch spinning. This is the name applied to the action of the male clutch member when it continues to rotate or spin after the clutch spring pressure has been released. With the male member connected up to the principal transmission shaft and gear, as is often the case, these members continue to rotate with it. This gives trouble mainly in gear shifting, for the member which is out of engagement is considered to be at rest or rapidly approaching that condition. When at rest, it is an easy matter to mesh another gear with this one; but when this one is rotating or spinning, it is not so easy, particularly for the novice.

Clutch spinning may be caused (1) by a defect in the design, in which case little can be done with it; (2) by a defect in construction—as in balancing, for instance, which can be corrected; or (3) it may be due to external causes, as for instance a bearing which has seized, due to a lack of lubricant, etc.

In any case, the best and quickest remedy is a form of clutch spinning brake. This may consist simply of a small pad of leather, or metal covered with leather, so located on the frame members that the male drum touches against it when fully released. Or it may be something more elaborate as to size or construction, or both. On many modern cars, in fact on practically all good cars, some form of clutch spinning brake is fitted. Thus in Figs. 50 and 60, metal cones of small diameter are provided; in Fig. 51 is found something similar with two V-grooves; while Figs. 56 and 59 show flat concentric disks.

TRANSMISSION

Primarily, the clutch is used to allow the use of change-speed gearing; or, stated in the reverse way, the form of the transmission determines whether a clutch must be used or not, there being cases in which it is not used. Thus, where the frictional form of transmission is used, no clutch is necessary, the frictional disks acting as a clutch and rendering another one superfluous. So, too, with the form of transmission known as the *planetary gear*, no master clutch is needed.

On the other hand, the reverse of this does not always hold. Any form of clutch may be used with the various other forms of transmission, as the sliding gear; in fact, in actual practice every known kind of a clutch will be found coupled with the sliding-gear transmission.

Classification. Broadly considered, there are five classes of transmissions used. In cases where the use of any one of these forms eliminates the final drive, this from its very nature does not alter the facts, but simply calls for a different and more detailed treatment. The five classes are:

(1) Sliding gear
- Selective
- Progressive
- Electrically operated
- Air operated

(2) Individual clutch

(3) Planetary or epicyclic

(4) Friction disk. Various spur and bevel arrangements

(5) Miscellaneous
- Belt and cables
- Hydraulic
- Electric
- Combinations of two or more

The features of the 1916 transmissions which stand out from previous years are: reduced sizes; simpler, lighter construction; greater compactness and greater accessibility. The smaller sizes have brought about the simplification and lighter weight, and in turn have been produced in answer to the popular demand for lighter weight cars. In part, simplification has been produced by unit power plants, now so popular.

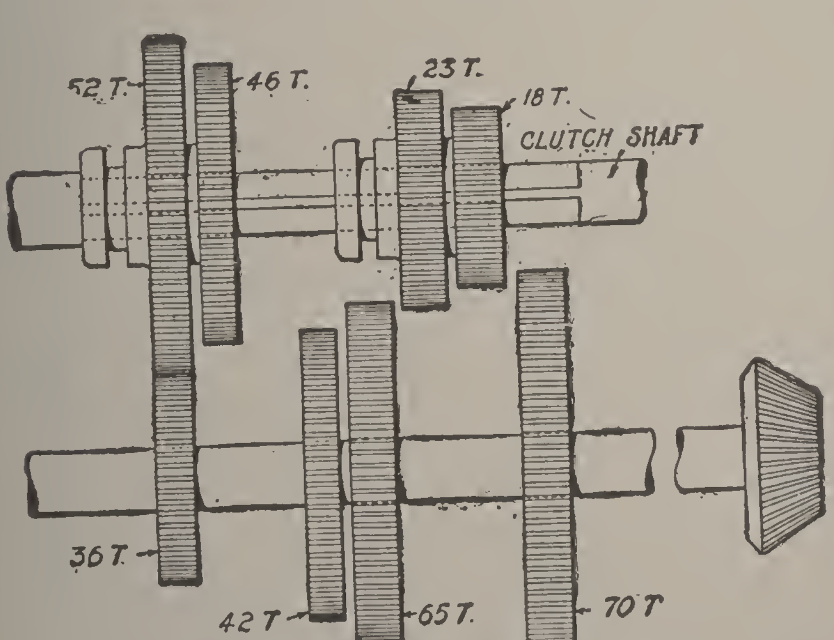

Fig. 68. Mercedes (German) 22-H. P. Selective Transmission

SLIDING GEAR

General Method of Operation. Of the different types of sliding gears, the first two subdivisions are not very closely marked, but blend somewhat into one

another. The only real difference between them is the method of operation, the names serving to indicate the distinctive characteristics. Thus, in a selective gearset, it is possible to "select" any one speed and change directly into it without going through any other. So, too, in the progressive form of transmission the act of changing gears is a "progressive" one, from the lowest up to the highest, and *vice versa*.

Selective Type. With the selective method of changing gears, it is possible to make the change at once from any particular gear to the desired gear without passing through any other, Fig. 68. Of course, the car will not start on the high gear any more than in the other case, but shifting into low for starting purposes is but a single action, accomplished quicker than it can be told. So, too, when the car has been started, it can be allowed to attain quite a fair speed and the change to high made at once without going through the intermediate gears.

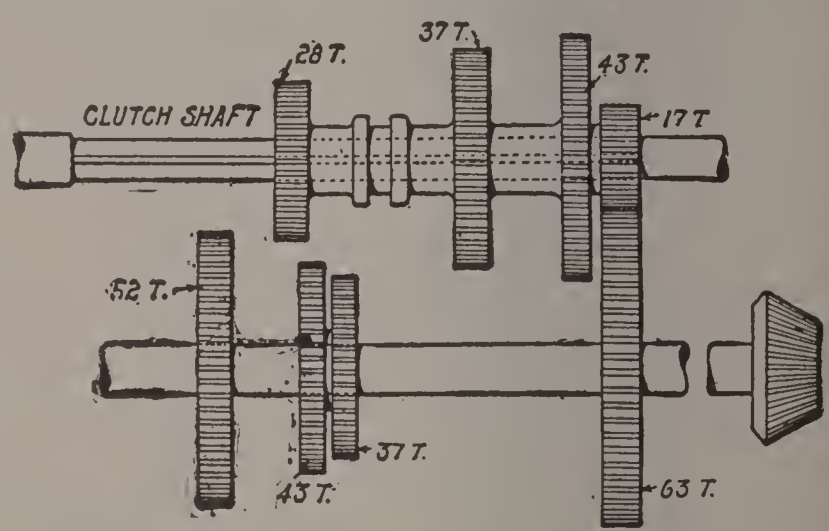

Fig. 69. Panhard (French) 22-H. P. Progressive Transmission

Progressive Type. Progressive gears are said to operate on the Panhard system, called after the originator of the system. This method leads to a number of troublesome occurrences; thus, in stopping it is necessary to gear down through all the higher speeds into low. If this is not done, when it is next desired to start the car it will be necessary to start the engine, throw in the clutch, drop from the gear in mesh to the next lower, from that to the next, and so on down to low, throwing the clutch out and in for each change of speed. When first is reached, the car may be started. After starting, it is then necessary, in order to obtain any measurable speed with the car, to change back up the list, from low to second, from second to third, and so forth. In this way the progressive gear is disadvantageous, since its use means much gear shifting; but, on the other hand, the shifting is very easy for the novice to learn, as it is a continuous process, all in one direction.

In Fig. 69 is shown the Panhard transmission for a car of 22 horsepower. This is a four-speed transmission, and to show graphically one big disadvantage claimed against this form as in favor of the selectively operated gears, refer again to Fig. 68. This represents the four-speed transmission used in the Mercedes cars of approximately equal power to the Panhard just described. The difference in the over-all length of the two is immediately noticeable, yet the only other difference is that the German cars are operated selectively and the Panhards progressively. Panhard and Mercedes

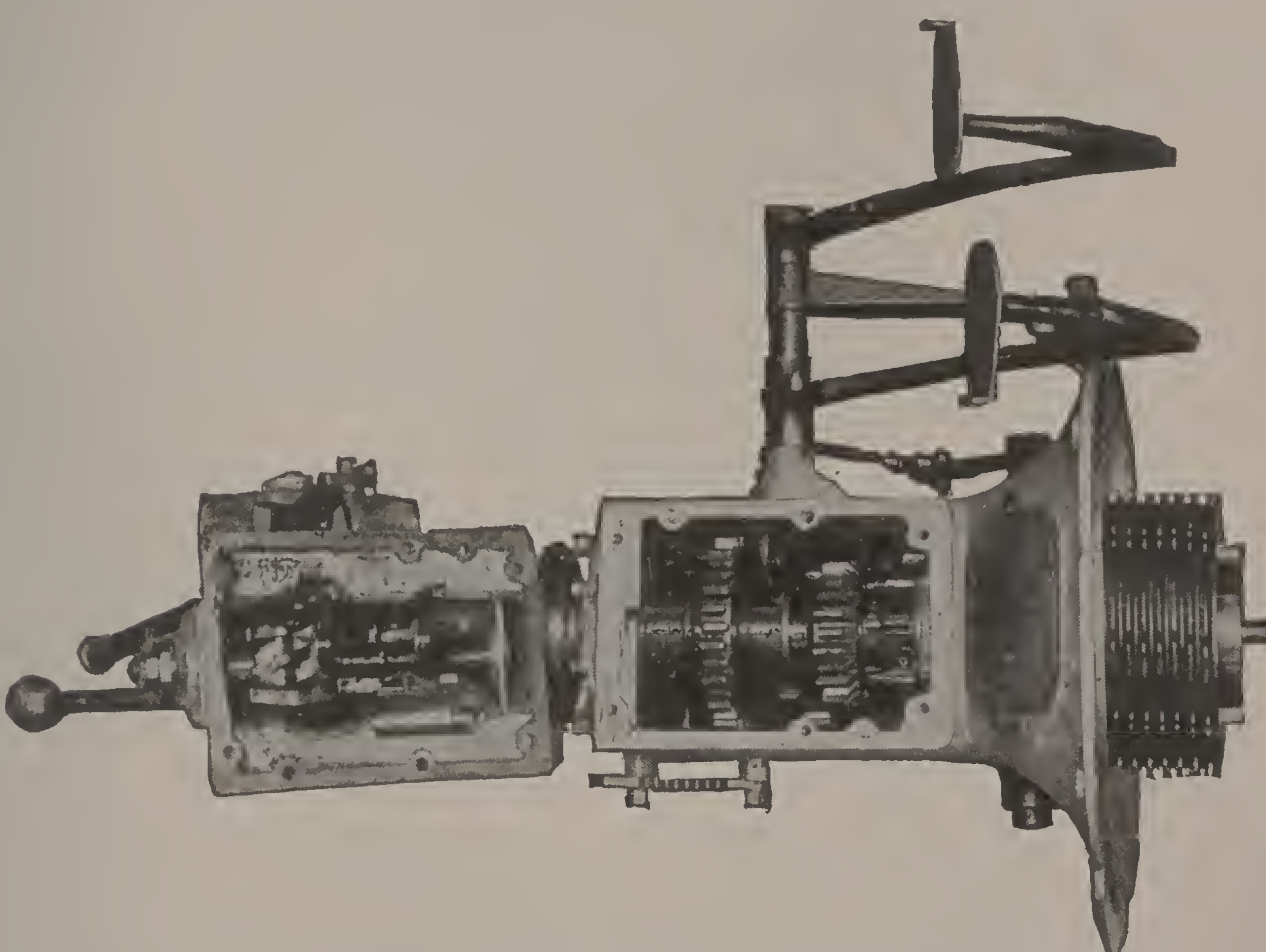

Fig. 70. Cadillac Transmission and Housing

have been consistent advocates of these two forms, the former adhering to its special type on a few models, even when this type passed out of popular favor. The latter, too, has always used the selective form of gear on all its cars, since the inception of this by Herr Maybach. In the United States, the progressive form has slowly but very surely gone out.

Modern Selective Types. To present some modern selective types of gear boxes, and point out their various differences, advantages and disadvantages, refer to Fig. 70. This type shows the three-speed selective gear used on the Cadillac cars, this being but

slightly modified from the type which has been used by this maker for three years. This change should be noted, however: the lay shaft, which formerly was on the same horizontal level as the main shaft, is now placed directly below it. This makes a higher but narrower gear box—that is, instead of being wide and fairly flat, it is now high and narrow. The placing of the shifting levers on the cover, directly over the center, has aided in making the gearset more compact than formerly. In it there are two shifting gears, one gear carrying a set of dogs cut into its face, which mesh with a similar set on the main driving gear to give high speed, which is the direct drive. The gear portion of this member meshes with another gear for second.

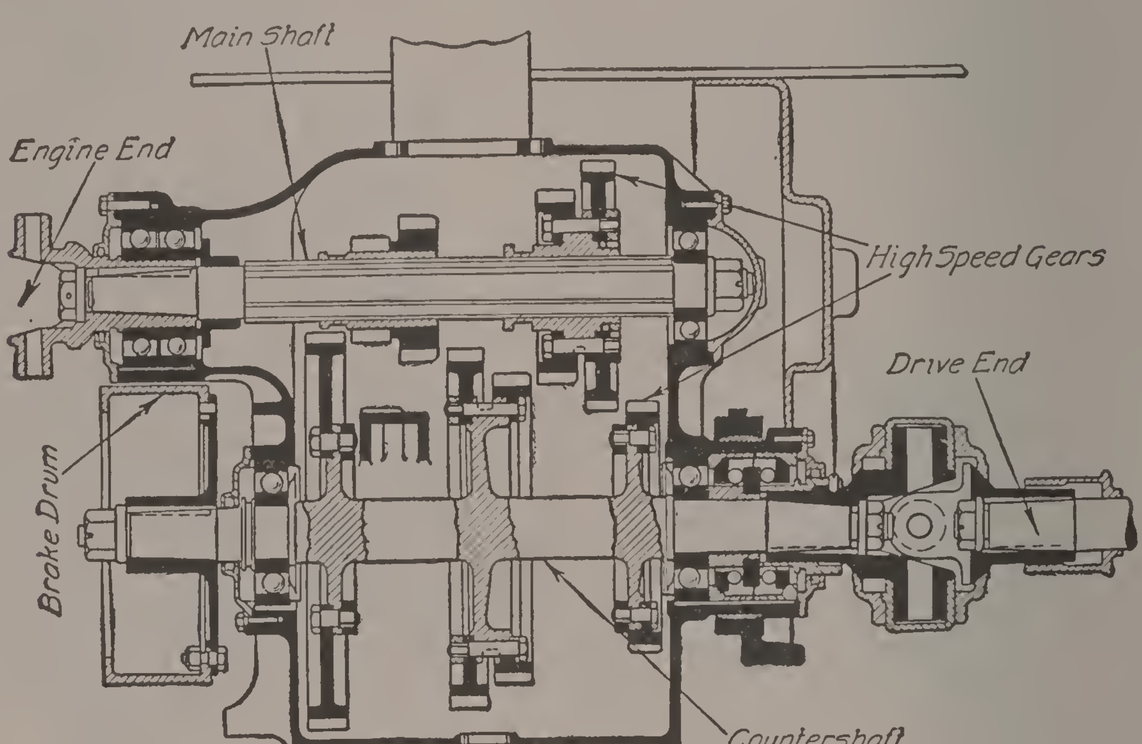

Fig. 71. English Transmission without Direct Drive

The second shifting member meshes with one gear on the lay shaft for low speed and with another on the third shaft for reverse. This last-named gear is at all times in mesh with the fourth lay-shaft gear, so that on reverse the drive is through five gears instead of four. On high gear the drive is through the dogs, the lay shaft being driven, of course, but silently, as it transmits no power.

Driving Off the Lay Shaft. As will be noted, in all the modern gears presented, the drive is off the rear end of the main shaft, the lay shaft serving only as a medium for speed reduction. It will be noted also that in all the original forms first shown, the drive was off the lay shaft; that is, the engine drove one shaft, while the other drove the wheels. This form was widely used in the early days, in

fact, it is now used to some extent, but mostly in England and on the Continent. An up-to-date English gear box with this form of drive

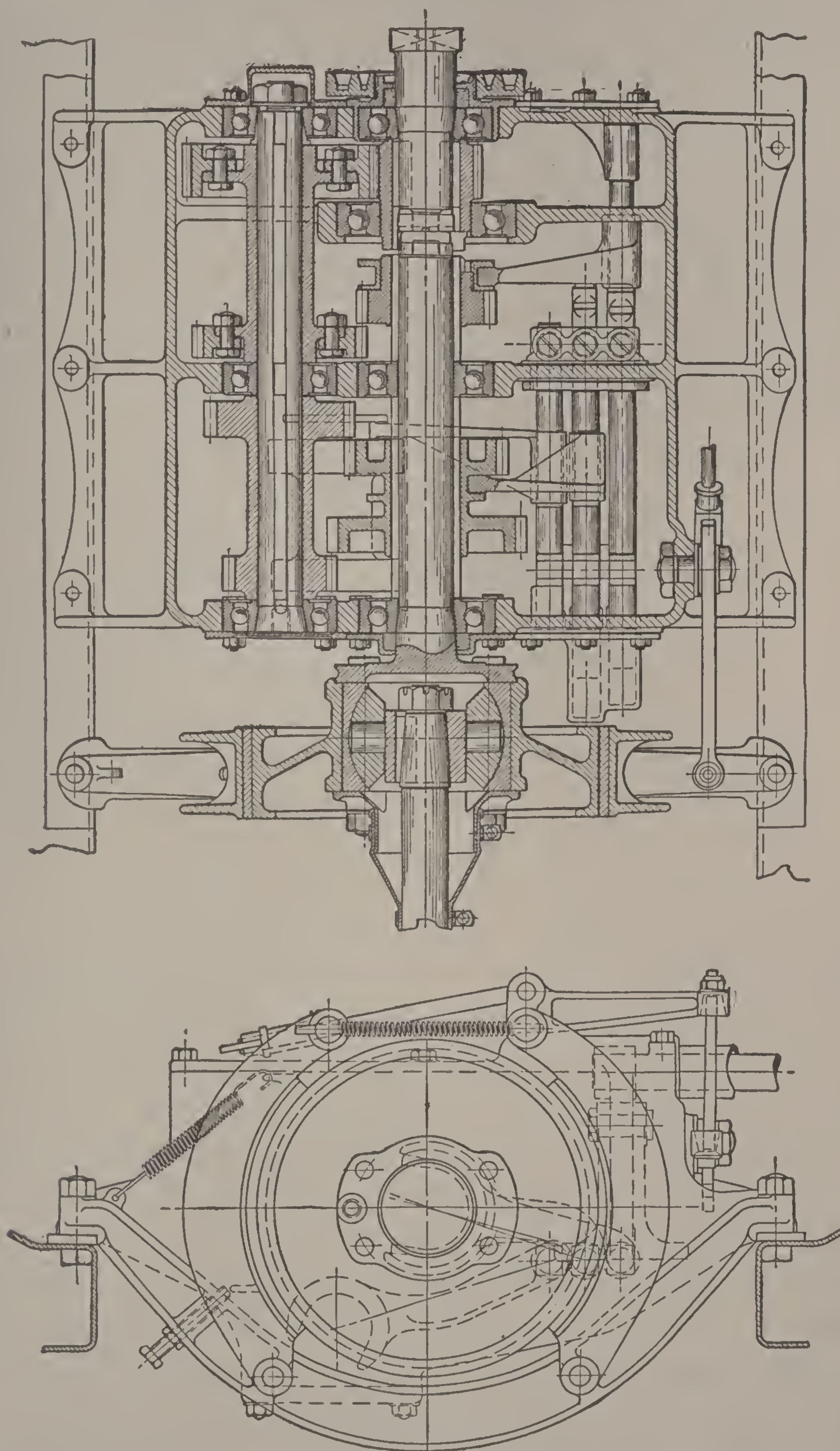

Fig. 72. Four-Speed Gear Box and Shaft Brake of Austin (English) Car

is shown in Fig. 71, this being of the three-speed selective type, the same as those previously shown.

Obviously, this construction makes it impossible to have a direct drive, and on all speeds the drive must be through gears. This makes all speeds noisy, which is the real reason why it has gone out of use. As will be noted in Fig. 71, this has both the shifting members on the main shaft, the gears on the lay shaft being of the bolted-on type. This is done to reduce manufacturing costs. Note the double-row ball bearing to take thrust at the driving end of the main shaft and the driven end of the lay shaft.

Four-Speed Type with Direct Drive on High. One of the tendencies of recent years has been the gradual change toward more speeds, as shown by the increasing use of four-speed gear boxes. Other indications of this have been the two-speed axle, which gave double the number of gear-box speeds, with the ordinary three-speed and reverse transmission; and the electric transmission, which affords seven forward and two reverse speeds.

An excellent example of the four-speed selective gear is the Austin (English), shown in Fig. 72. As will be noted, the two shafts are set side by side, running entirely on ball bearings. A notable feature is the introduction of an extra bearing in the center of each shaft, which, with the web of the case, forms the bearing supports and practically divides the case into two parts. In addition, an extra bearing-support will be noted on the main driving gear at the left. High speed is a direct drive by means of dogs on high gear and on the first shifter. For second, this is shifted to the right. For third, the second shifter is moved to the left; and for low, to the right. Reverse is gained by setting the second shifter in the neutral position as shown, and shifting another pair of gears beneath the third speed and the small end of the shifter. An interesting feature of this unit is the spherical ball joint at the drive nend and the transmission brake, which is outside of this, and which is supported from the sub-frame at that point.

The form of final drive alters the construction of the transmission very materially. Formerly, when all final drives were of the double-chain form, it was customary to include the differential, bevel gears, and driving shafts in the gear box. Now that the chain has gone out, this construction is found only when the gear box is a unit with the rear axle.

Just for comparison with the domestic product, the transmission

of the Horch, a famous German car, is shown in Fig. 73. High speed is obtained with direct drive by meshing gears *A* and *D*, through a gear not shown, cut in the face of *A*. Second is obtained by the combination *A*, *B*, *C*, and *E*. Third is given by *A*, *B*, *F*, and *G*. Fourth is produced by *A*, *B*, *H*, and *I*, while a still further movement to the right of this second train gives the reverse. Attention is specifically called to the device for throwing the lay shaft out of gear when the high speed is engaged, this resulting in no gears running on the direct drive, that is to say no gears meshing face to face. The result is an absolute lack of gear-box noises on high speed. High speed is effected by the final movement of the shifting rod to the left, which actuates the high gear.

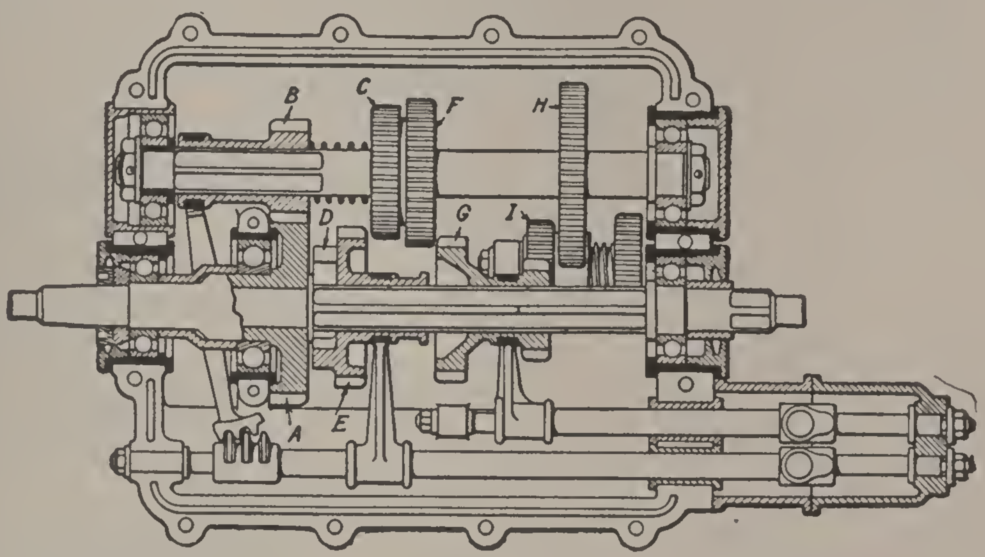

Fig. 73. Horch (German) Four-Speed Selective Transmission

The partial worm engages a sector so pivoted in the middle as to slide the gear *B* to the right, and enough to throw it out of mesh with *A*, when the shaft is moved so as to introduce gear, or rather, jaw clutch *D* into its mate within *A*.

Four-Speed Type with Direct Drive on Third. In all the transmissions shown and described thus far, the direct drive has been the highest speed. By referring back to Fig. 55, which showed the Winton four-speed gear box, as well as the clutch, a point of difference will be seen. This has the direct drive on third speed, fourth being a geared-up speed for use only in emergencies, when the very highest rate of travel is required, and when a little noise more or less would make no difference. This arrangement of the direct drive and silent speed has long been a debated point, some designers favoring the type just shown with an over-geared speed for occasional use, while

the opponents of this say that this construction practically reduces the transmission to a three-speed basis, the fourth being so seldom used that it is practically negligible. They say, also, that the modern motor can attain a high enough speed on the one hand and is flexible enough on the other to permit its being used with the high-gear direct drive upon almost all occasions.

Electrically Operated Gears. In substance, the electrically operated transmission has all the hand levers, rods, and other levers replaced by a series of push buttons. When it is desired to change speeds even before the actual change is necessary, in fact, the driver presses the button marked for the speed he thinks he will require. Then, when the actual need becomes apparent, he throws out the clutch and immediately drops it back again, all this forming but a single forward and back movement of the foot. During the slight interval while the clutch is out, the electrical connections shift the gears automatically, so that when the clutch is let back, the gears are meshed ready to drive.

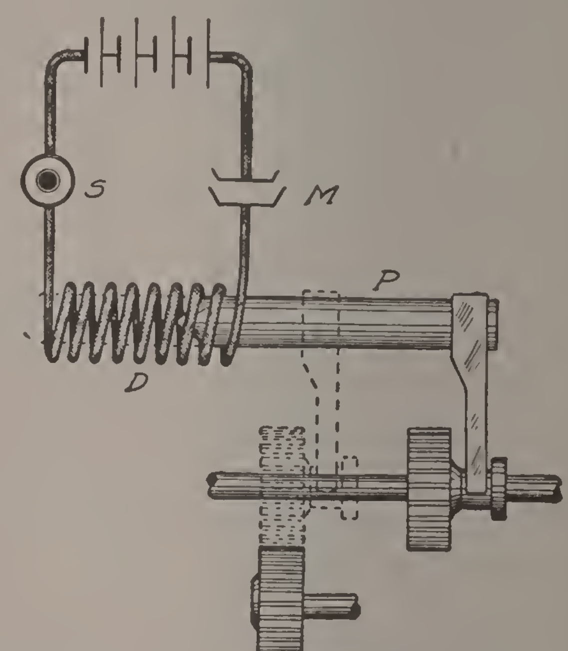

Fig. 74. Sketch Showing How a Solenoid Moves a Gear When Current Flows

Principle of Action. To explain this action briefly, the gears are moved by means of solenoid magnets, which are nothing more than coils of wire, through which an electric current from a convenient battery is allowed to pass. Through the center of each one of these coils passes an iron bar. When a current passes through the coil, it is converted into an electromagnet and draws the iron bar inward. As the other end of the bar is connected to the gear to be shifted, this movement of the bar shifts the gear. Consequently, when the button is pressed so that current flows through one of the coils, that action shifts the gear for which the button is marked.

By referring to Fig. 74, this action will be made more clear. The diagram shows but one pair of gears to be meshed, and the battery, push button *S*, coil *D*, iron bar *P*, and clutch connection *M* are all shown as simply as possible. When button *S* is pressed, current through the coil *D* will draw the bar *P* and mesh the

gears, as soon as the clutch has been thrown out, thereby closing the circuit at M. The application of this to an actual transmission is shown more in detail in Fig. 75. This shows the clutch pedal

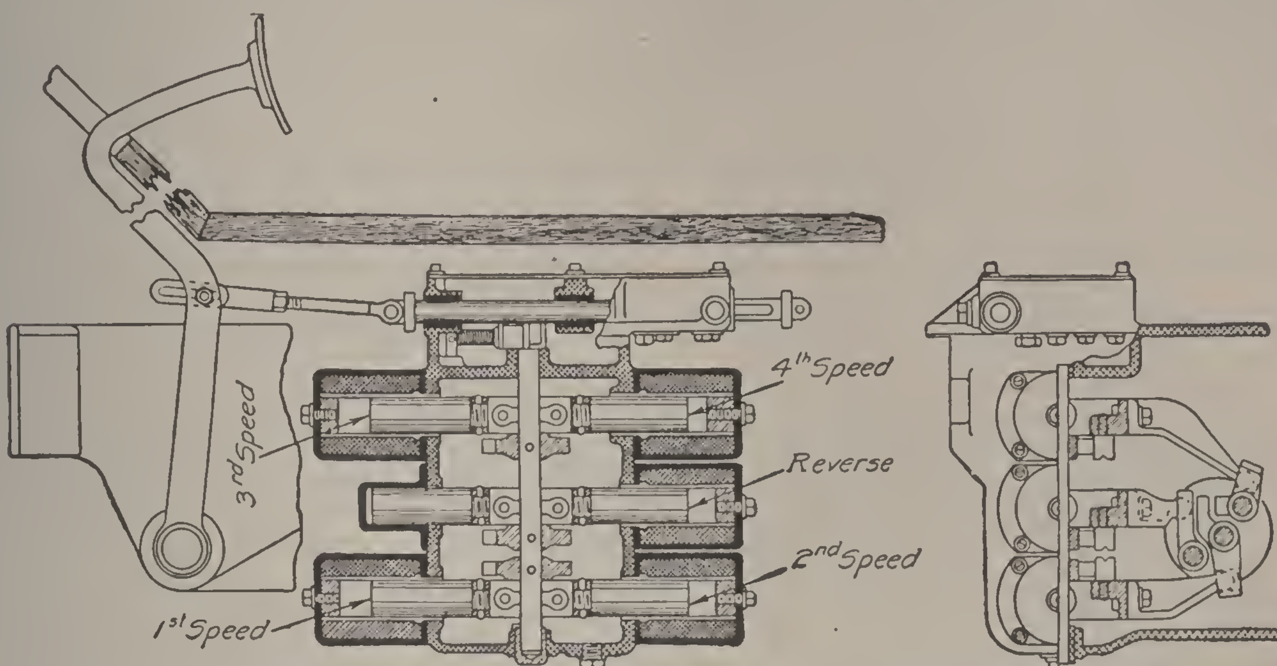

Fig. 75. Arrangement of the Solenoids and Pedal in the Vulcan Electric Gear Shift

and its connection to the six solenoids necessary to produce four forward speeds, one reverse, and a neutral point.

On the steering wheel, Fig. 76, the control group of six buttons will be noted on the small round plate at the center, with the addition of the horn button in the center. In Fig. 77 is another arrangement.

In the 1916 forms of electric control systems, the buttons are

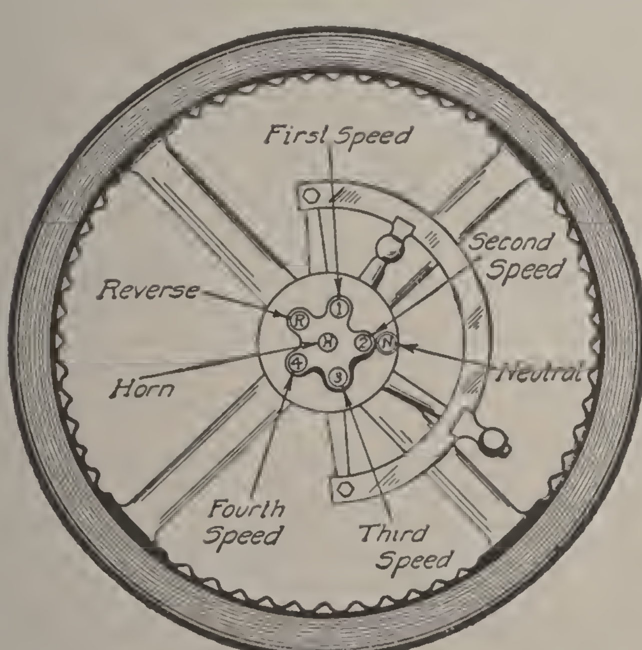

Fig. 76. Arrangement of Buttons for Gear Shifting

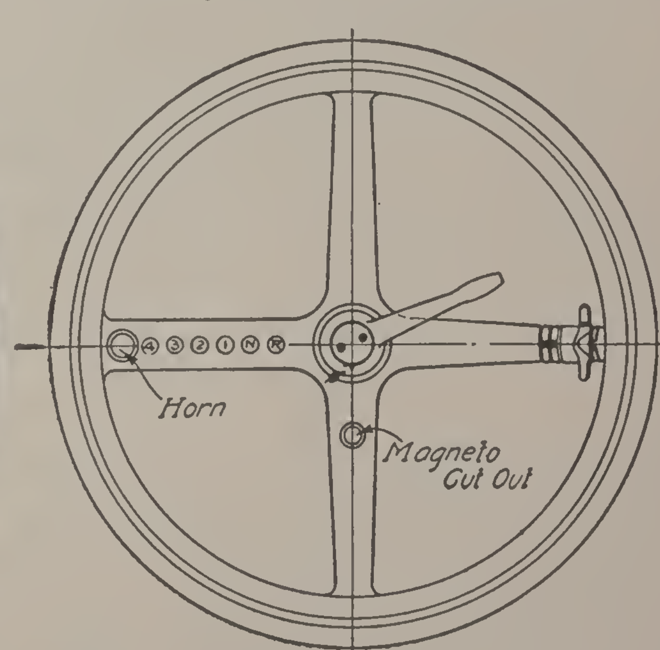

Fig. 77. Another Arrangement of Buttons for Gear Shifting

grouped in one case; on the top of a small box about four or five inches square, which is placed on the steering post below the wheel in another on the dash, and in a third on a rod connecting post and dash.

Pneumatic Shifting System. The pneumatic system of gear-shifting is along lines somewhat similar to the electric system, air under pressure being used to move the gears, instead of a hand lever and rod combination. For this purpose it is necessary to add to the car an air compressor, a tank to carry the compressed air, and what is called the "shift"—really a complicated valve and a series of plungers. The valve and plungers respond to a finger lever on the steering wheel, the same as the electric system responds to the buttons, air being admitted behind the plungers, which move the gears

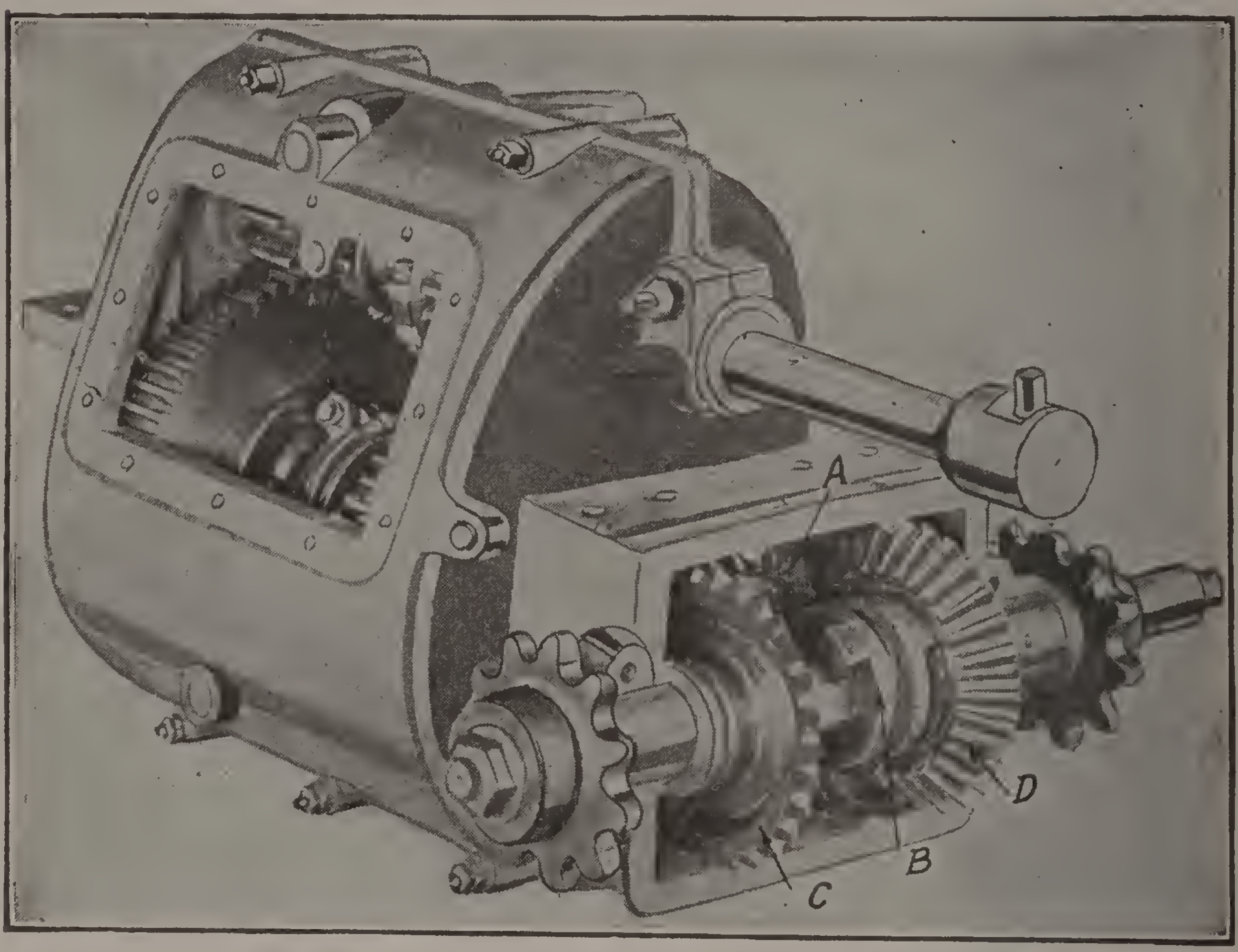

Fig. 78. Form of Gear for Gasoline Railway Car

as soon as the clutch is depressed. It is seen, therefore, that this system, like the electric shifter, permits the anticipation of the car's needs.

Railway Car Needs. All transmissions previously presented have had but one reverse. For gasoline railway cars, the inability to turn requires as many reverse speeds as forward, which means special gearing, as shown by Fig. 78. This is the type used by the Sheffield Car Company, Three Rivers, Michigan, in their gasoline-driven railway cars. The driving bevel, faintly seen at *A*, instead

of driving but one bevel, as is usual, drives two, *C* and *D*. Each one of these is free on the shaft, being bushed to reduced wear, but between the two is a sliding member *B*, with jaw clutches formed on both faces. This slides on a squared shaft, and the jaw clutches match jaw clutches formed in the inside face of the two driven bevels. When slid to the right, then, *B* engages with jaw clutches in gear *D*, and thus drives it. If, then, the gear box gives three speeds, all three may drive through this combination, giving the forward speeds. If it is desired to drive in the other direction, the clutch member *B* is slid out of mesh with *D* and into mesh with *C*, thus reversing not only the direction of motion but also the direction of all speeds.

Rear Axle Combinations. Aside from the railway form, the location of the transmission varies its form. The front location for the engine is now universal, but this cannot be said about the gear box. This unit, on the contrary, is placed in every conceivable position, sometimes forming an integral part of the rear end of the engine and even being removed to form a part of the rear axle and differential housing.

TRANSMISSION TROUBLES AND REPAIRS

Noise in Gear Operation. One of the most common of transmission troubles is noise in the operation of the gears, generally a grinding sound. This is heard more in bevels than in spurs, but in old transmissions and on the lower speeds it is heard frequently. A good way to quiet old gears, after making sure that they are adjusted rightly and meshing correctly, is to use a thicker lubricant. If thick oil is being used, change this to a half-oil half-grease mixture or even go so far as to use an all-grease mixture of fairly thick consistency.

In this respect the repair man or amateur worker may take a leaf out of the book of second-hand car men, who are said to "load" an old and very noisy transmission gear with a very thick almost hard grease in which is mixed some shavings, sawdust, cork, or similar deadening material. When this is done, a graphite grease is generally used, so that the shavings, cork, etc., would not show in case it was necessary to take off the gear-box cover. This material will fill up all the inequalities of the gears and shafts so that tem-

porarily, everything fits more tightly, and in addition all the sounding-board, or echo, effect is taken out of the transmission case. This sounding-board effect is fully as important as the former, for many really insignificant noises are magnified, by poorly shaped gearcases, so as to appear very loud, indicating serious trouble which needs immediate attention, when such is really not the case.

Another source of gearset noise is a shaft out of alignment, caused either by faulty setting, by worn or loose bearings, or by yielding or cracking of the case. If it is properly set at one end and is out at the other, the trouble will be more difficult to find and remedy.

Heating. Heating is a common trouble, too, but usually this can be traced to lack of lubricant in an old car, of too large shafts or too small bearings in a new one. Sometimes the grease used will

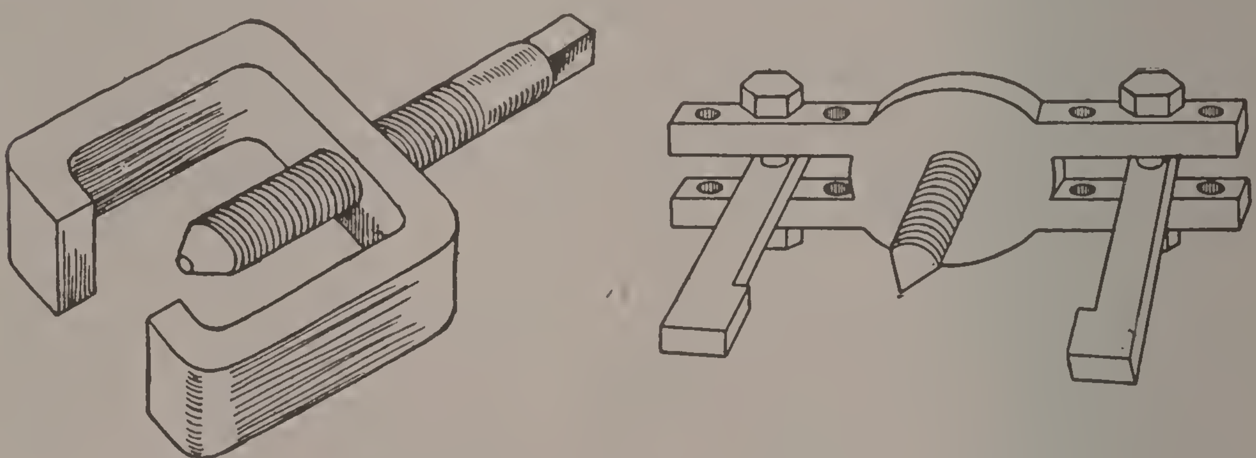

Fig. 79. Types of Gear Pullers

cause heating, particularly when long runs are made with the transmission working hard. This is most noticeable when the grease or lubricant is of such a consistency that the gears simply cut holes in it but do not carry any around with them, or do not otherwise circulate the lubricant. This can be remedied by making it thicker so the gears will cut it better, by making it thinner so they will splash it more, or by changing the nature of it entirely to a form which is more sticky and will adhere more tightly.

Gear Pullers. One of the principal necessities for transmission work is a form of gear puller. These are like wheel pullers, except that they are smaller and more compact. In Fig. 79, a pair of these are shown. The one at the left is very simple, consisting of a heavy square bar of iron which has been bent to form a modified U. Then, a heavy bolt is threaded into the back of this or bottom of

the U. This will be useful only on gears which are small enough to go in between the two sides of the puller, that is, between the sides of the U, which in use is slipped over the gear, the screw turned until it touches something solid as the end of the gear shaft, and then the turning continued until the gear is forced off.

While not as simple as this, the form shown at the right has the advantages of handling much larger gears, and also of being adjustable. As the sketch shows, this consists of a central member having slotted ends in which a pair of L-shaped ends or hooks are held by a pair of through bolts. Then there is a central working screw. To use, the hooks are set far enough apart to go over the gear, then slipped around it and hooked on the back. The central screw is turned up to the end of the shaft, and then the turning continued until the gear comes off. There are many modifications of these two, in fact practically every repair shop in the land has its own way of making gear or wheel pullers. At any rate, every shop should have one.

Care in Diagnosis. The repair man should use a great deal of care in doping out or diagnosing the trouble in a transmission, for frequently what appears at first to be at fault turns out to be all right; or else something is back of the first trouble which must be corrected before a remedy can be applied. Thus, recently, a repair man figured that a new gear was needed to repair a transmission. This was received from the factory three days later, and when he started to put it in, he found that a bearing was defective; in fact, the defective bearing caused the wear in the gear. This necessitated a further delay of three days in order to get a new bearing.

Poor Gear Shifting. A common transmission trouble is poor gear shifting. This may be due to a number of different things. For one thing the edges of the gears may be burred so that the edges prevent easy meshing. When this is the case, any attempt to force the gears into mesh only burrs up more metal and makes the situation worse. Whether this is the trouble can be determined very quickly and easily by removing the transmission cover and feeling of the gears with the bare hand; the burred edges can readily be distinguished. If this is the only fault, the transmission should be taken down, the gears taken out and placed in a vise, and the burrs removed with a cold chisel and file.

Poor or worn bearings or a bent shaft or one not accurately machined may cause difficult shifting. If the bearings are worn, the difficulty of shifting will be accompanied by much noise, both in shifting and after. The bent shaft is more difficult to find and equally difficult to fix, a new shaft probably being the quickest and easiest way.

Sometimes the control rods or levers bind or stick so that shifting is very difficult. In case the gears are difficult to "find" or will not stay in mesh, the fault may be in the shifter rod in the transmission case. This usually has notches to correspond to the various gear positions, with a steel wedge held down into these notches by means of a spring. The spring may have weakened, may have lost its temper, may have broken, or for some other reason failed to work. Or with the spring in good working condition, the edges of the grooves or notches may have worn to such an extent as to let the wedge slip out of, or over, them readily.

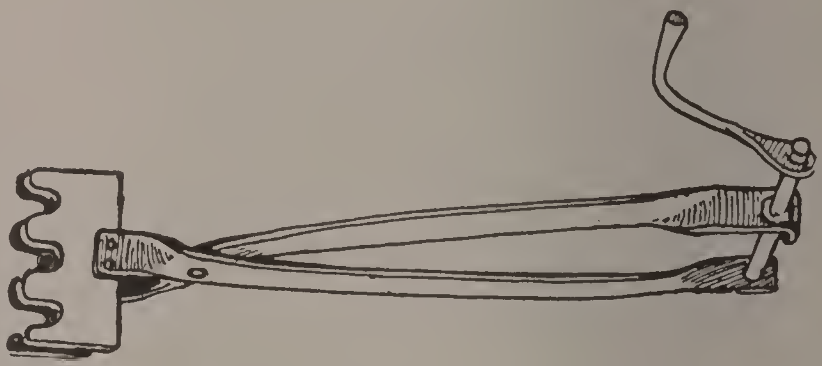

Fig. 80. Handy Spring Tool for Ford Assembly

Handy Spring Tool. In the Ford transmission band assembly there are three springs, which it is difficult to assemble because of the trouble in holding so many things at once. To eliminate this trouble the tool shown in Fig. 80 can be constructed, this being made from flat bar stock. The handles, if they could be called that, are pivoted together and carry at one end a kind of flat jaw with three notches. When the two of these are squeezed together by means of the screw and handle at the other end, the flat plates will hold the three springs tightly enough so that all can be inserted in their proper positions at once, and by using but one hand. Tools of this kind, which save a great deal of the workman's time and thus save both time and money for the owner of the car, should, and in fact do, distinguish the good well-equipped repair shop and garage from the old-fashioned kind which is only in the business for the money, and not too particular how to get it.

In transmissions of the planetary type, there is little or no

trouble except with the bands. If these are loose, the gears will not engage and the desired speed will not result. If they become soaked with grease, oil, or water, they will not work as well as if kept clean, and in the case of excessive grease, will slip continually. If the band lining becomes worn, it should be treated just as a brake lining is. When inspected for wear and found not badly worn but slippery, it may be cleaned in gasoline and then in kerosene, after which a saw, hacksaw, or coarse file may be used to roughen it. Sometimes greasy bands can be fixed temporarily—say, enough to get the car to a place where tools, materials, and facilities for doing the work are available—by sprinkling on powdered rosin or fuller's earth. The former should be used sparingly because it will cause the band to bite or grab hold when forcibly applied, and at times has been known to cut into and score a cast-iron drum. In general, as stated previously, planetary transmission bands should be handled in the same way as ordinary brake bands, as to lining and relining, roughness of surface, lubrication, etc.

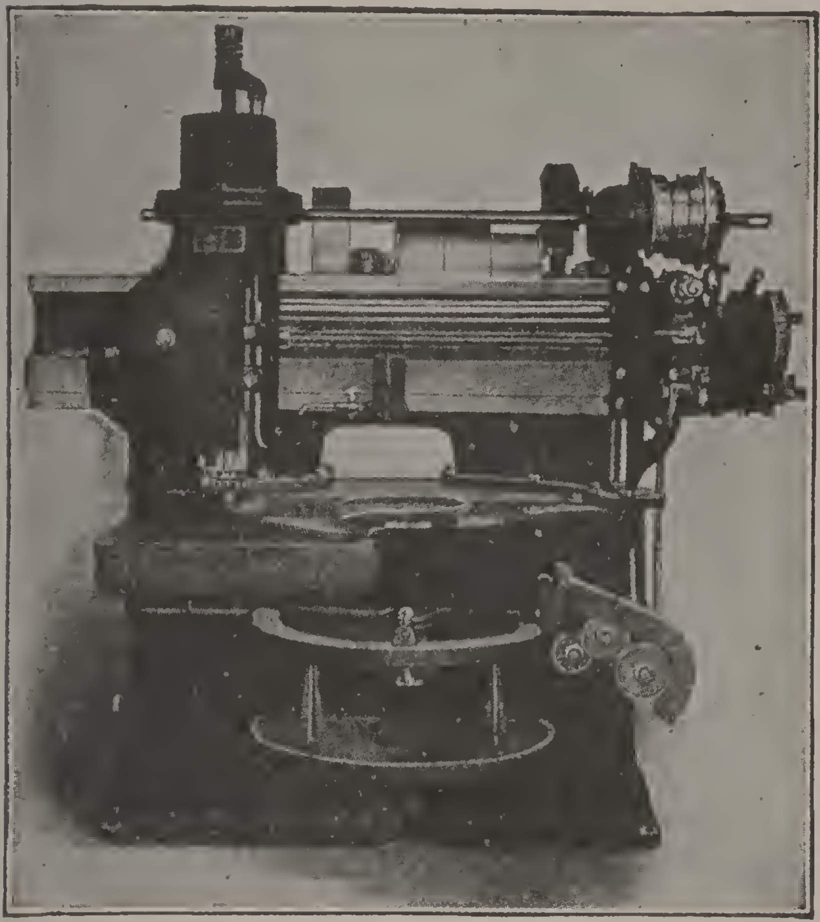

Fig. 81. Fellows Shaper for Cutting Gear Teeth

GEARS

Since the whole subject of transmission concerns itself with gears, it will not be out of place to discuss the gears themselves and describe the many different kinds in use. Speaking broadly, the gears used may be classified according to the position of their axes, relative to one another. Thus we have axes parallel and in the same plane; parallel but not in the same plane; at right angles and in the same plane; at right angles and not in the same plane; at some

other angle than a straight or a right angle and in the same plane; and the same, but not in one plane. These classes give us the forms of gear in common use, viz, spur gears, bevel gears, helical gears, herringbone gears, spiral gears, and worm gears.

Spur Gears. A spur gear is not only by far the most common kind of gear, but is also the easiest to describe, consisting as it does of a round flat disk with teeth cut in its circumference, i.e., around the periphery of the disk. The cutting of these teeth has had much to do with their universal use, since the very low cost of cutting the teeth, due to special machinery developed for that purpose, just about explains the matter. Formerly, the teeth were cut, one gear at a time, in the milling machine, this being practically a hand operation, since all movements of the gear or cutter had to be made by hand. Later, improvements made it possible to cut more than one gear at a time, which resulted in lowering the cost, but did not eliminate the hand work.

Step by step special machinery was developed for this work, until finally a perfected machine was brought out which does all the work. With this machine, the workman places the cutter on the machine spindle, sets the gear blanks into position, and starts the machine, after which it goes on automatically cutting tooth after tooth to a correct shape, until the gear is finished, when the workman is again necessary to shut it off, and, after taking out the finished gears, put in a fresh supply of gear blanks.

This machine, known as the *Fellows gear shaper*, Fig. 81, has reduced the manual labor of gear-cutting to such a point that it is possible for one man to operate, unassisted, from three to six machines at one time. Usually, these are placed together and located near the automatic machinery, a group of them being called a *battery*. By having a battery of five machines cared for by a single man, the cost of spur-gear cutting has been brought down to the absolute limit.

Bevel Gears. Bevel gears, in which the shafts are at right angles and in the same plane, or in the same plane but not at right angles, are more difficult to cut and therefore less used. Their cutting is now done, like the spurs, in an automatic, or nearly automatic, machine, which requires little attention, but it does require more care than the spur-gear machine. Both spurs and bevels

sometimes require a chamfered tooth-edge, spur gears as used in the Panhard or clash-gear transmission always being in need of it. This work was formerly done by hand, but now a special machine has been manufactured for this purpose.

There are no real restrictions against the use of the spur and bevel, either or both being used interchangeably. Very often they are used in combinations, which appear peculiar, as the one shown in Fig. 82. This is the final drive and reduction gear of the Autocar commercial cars, made by the Autocar Company, Ardmore, Pennsylvania. In this it will be noticed the drive from the engine is to an intermediate shaft through bevels and final drive by spur gears.

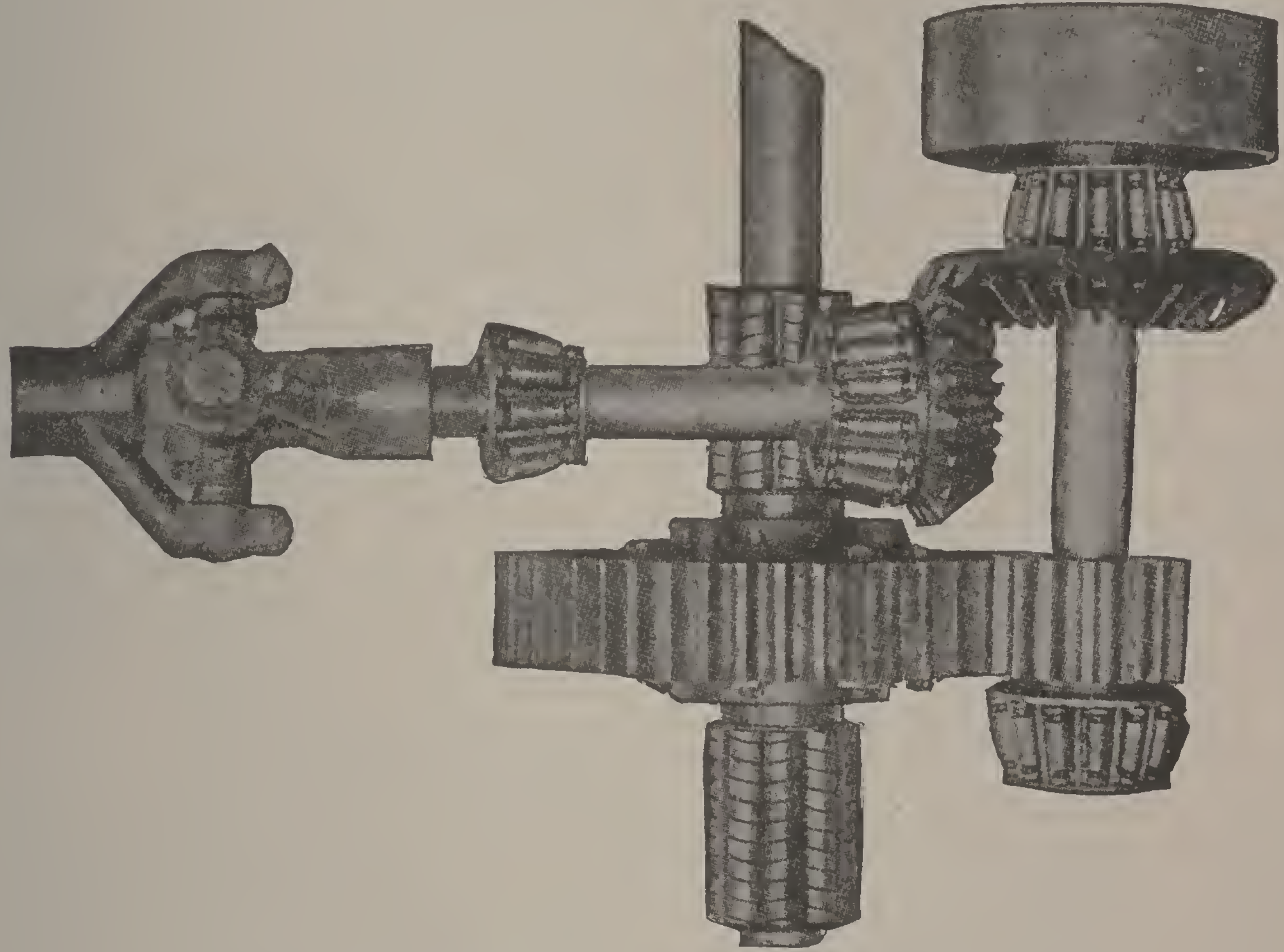

Fig. 82. Combination of Gears in the Autocar Final Drive

Helical and Herringbone Gears. In situations where quiet running is deemed necessary, the use of a helical gear frequently finds favor, since it accomplishes the desired result, although the cost of cutting is high. Of late, these have come into general use for camshaft drives and similar places. A pair of helical gears set so that the helices run in opposite directions, forms a herringbone gear. This is even more quiet in its action than the single helix, and pos-

sesses other virtues as well. One well-known firm has adopted it for camshaft driving gear, and makes it, as described, to save cutting-cost, as the cost of cutting a true herringbone would be prohibitive. So, a pair of helical gears of opposite direction are set back to back and riveted or otherwise fastened together, forming a herringbone gear at a low cost. Both of these may be used when the two shafts are parallel and in the same plane, but for cases where the shafts are neither in the same plane nor parallel, some form of spiral gear must be used.

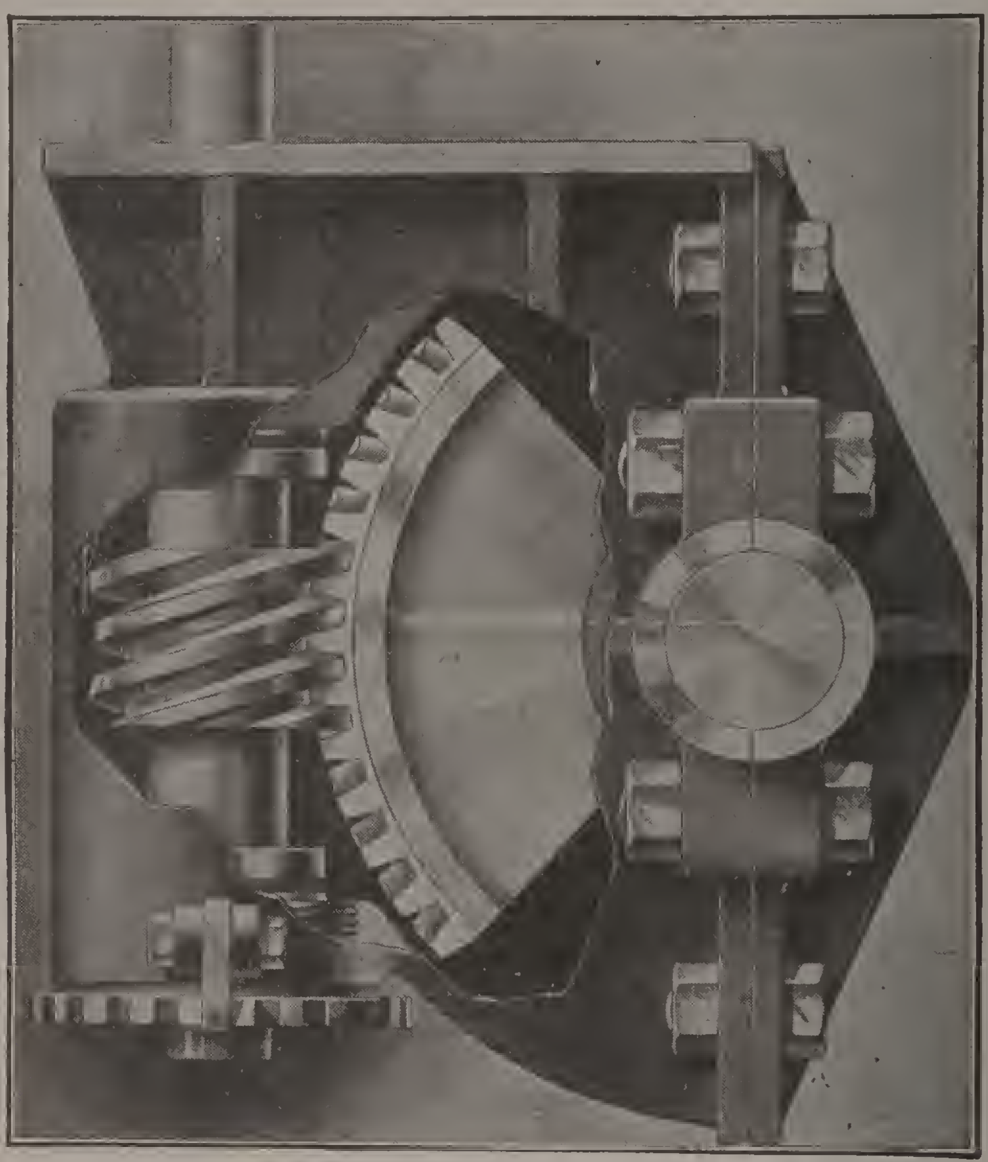

Fig. 83. Hindley Worm Steering Gear for Heavy Trucks

Spiral Gears. Spiral gears, as such, not being generally understood, and that variety of the spiral known as the *worm* gear being very simple and easily understood, the latter has attained much popularity within the past few years. This has been due in part to superior facilities for cutting correct worms and gears, but, in the main, to a superior knowledge of the principles upon which the worm works, and the things which spelled failure or success. Thus, one of the earliest experimenters in this line laid down the law that the

rubbing velocity should not exceed 300 feet per minute if success was desired, or in rotary speed about 80 to 100 revolutions. For automobile use, this was out of the question; but later experimenters found that these results only attached to the forms of gear used by the early workers, and did not apply to a strictly modern gear laid down on scientific principles.

The mistake made was in the pitch angle of the worm, which was formerly made small, nothing over 15 degrees being attempted. This was the item that was at fault and caused this very useful and efficient mode of driving to fall into disuse. As soon as this fact was ascertained and larger pitch angles utilized, better results were attained, until with 20-degree angles, 700 feet per minute pitch-line velocity was attained, followed shortly by the use of even higher angles, resulting even more successfully. As the efficiency depends

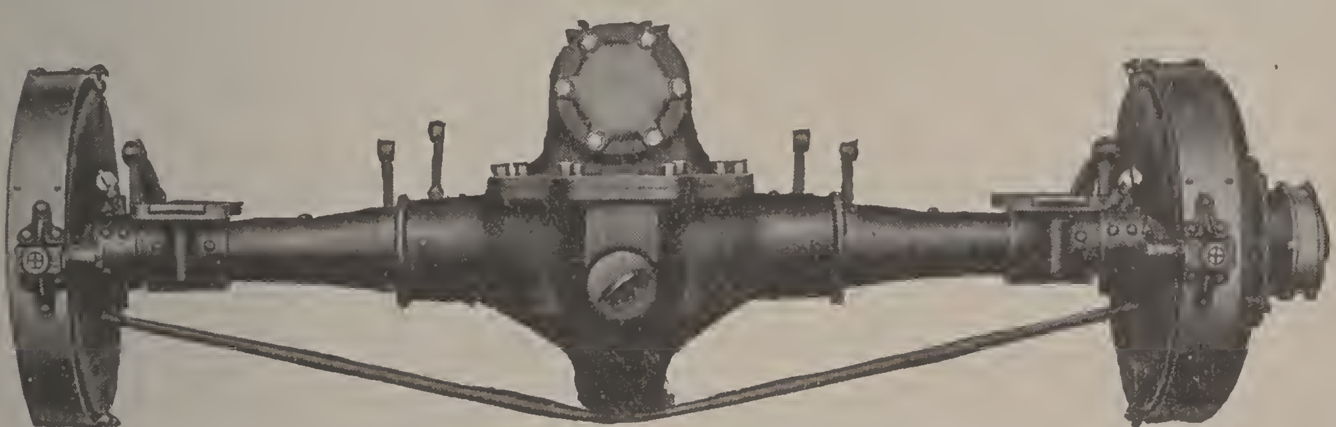

Fig. 84. Rear View of Timken Worm-Driven Rear Axle
Courtesy of Timken-Detroit Axle Company, Detroit, Michigan

directly upon the pitch angle, these changes brought the efficiency of this form of gearing from the former despised 30, 40, and sometimes 50 per cent up to 87, 88, and even 90 per cent, thus putting it on a par with any but the very best of spur gears, and above bevel gearing. In fact, in the light of modern knowledge of worm gears, it could easily be said without departing from the truth that it is possible to obtain from this form an efficiency of 93 per cent. In automobile work it has been used mostly for steering gears and final drives. For the former its irreversible quality is brought out, while for the latter this must be made subordinate to a great reduction, which may be attained in a very small, compact space. Many modern machines make use of worm gears: as Jeffery, and the Baker, Detroit, Hupp-Yeats, and Woods electrics; Pierce, Packard, Locomobile, Mack, Atterbury, Blair, Chase, Gramm, G. M. C., Hulburt,

Moreland, Standard, Sterling, and other trucks; Dennis (English) busses and trucks, and Greenwood and Batley (English) trucks. Among those using the spiral bevel may be noted Packard, Cadillac, Reo, Stearns-Knight, Velie, Kline, Apperson, Buick, Chalmers, Chandler, Cole, Haynes, Hupmobile, Jackson, King, Locomobile, and

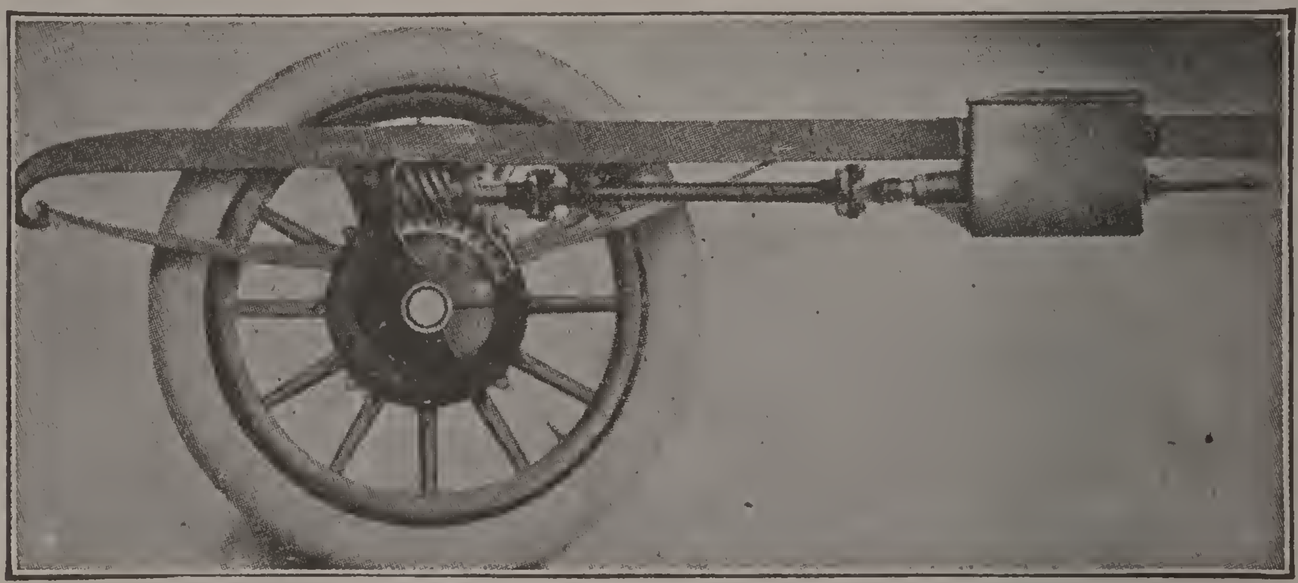

Fig. 85. Worm Gear Applied to Rear Axle Drive of Touring Car

many others. Figs. 83, 84, 85, and 87 show applications of the worm, and Fig. 86 shows a separate detail of a worm as used on a prominent truck.

Spiral Bevels. The spiral bevel is a new development, having been brought out in 1914 as a compromise between the worm and the straight bevel. As such, it is supposed to have practically all the advantages of both, except that it does not afford the great speed

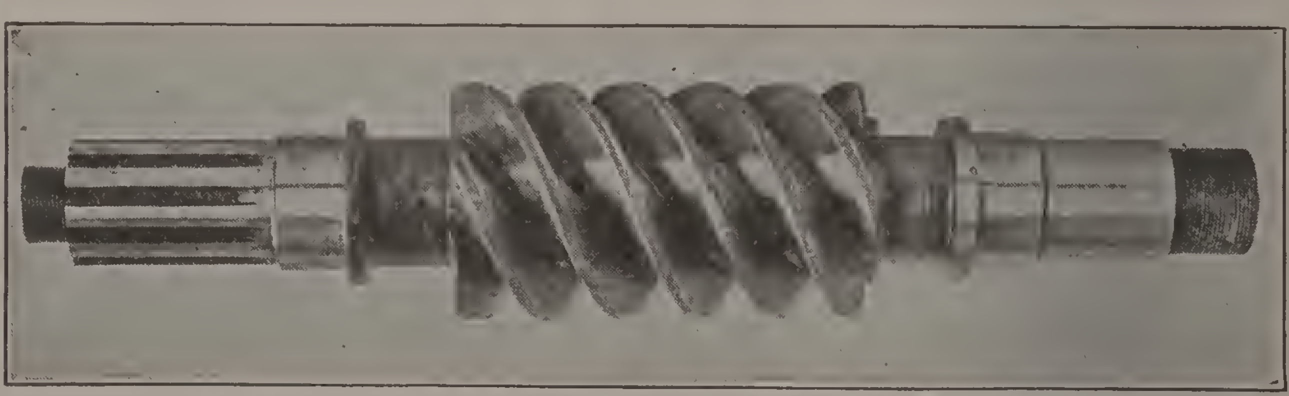

Fig. 86. Worm Used on Locomobile Trucks
Courtesy of Locomobile Company of America, Bridgeport, Connecticut

reduction that can be accomplished with a worm in the same space, being more like the bevel in this respect.

Worm Gears. Progress in the application of worm gears for rear-axle use has been considerable in the last few years. In one respect, at least, designers have found it an advantage. The top

position for the worm was not much used at first, as it was thought impossible for it to receive sufficient lubricant there. Consequently, it was always placed in the bottom position, which cut down the clearance considerably; in fact, in this position the clearance was less than with the ordinary bevel. With the proof that the worm could be lubricated in a satisfactory manner in the top position, the majority of them are so placed, thus converting what was formerly a disadvantage into an advantage, for in the upper position the clearance is greater than with bevel gears. This is shown quite clearly in Fig. 84, where it will be noted that the worm-gear housing in the center is actually higher than are the brake drums at either end of the axle. This too, despite the fact that a truss rod passes beneath the center of the axle. For heavy trucks especially, and for pleasure electric cars, the worm has proved an ideal drive. In these situations there is the condition of high engine or electric-motor speed, coupled with low vehicle speed requirements, which necessitate a considerable reduction. As pointed out, the worm gives this in a small space.

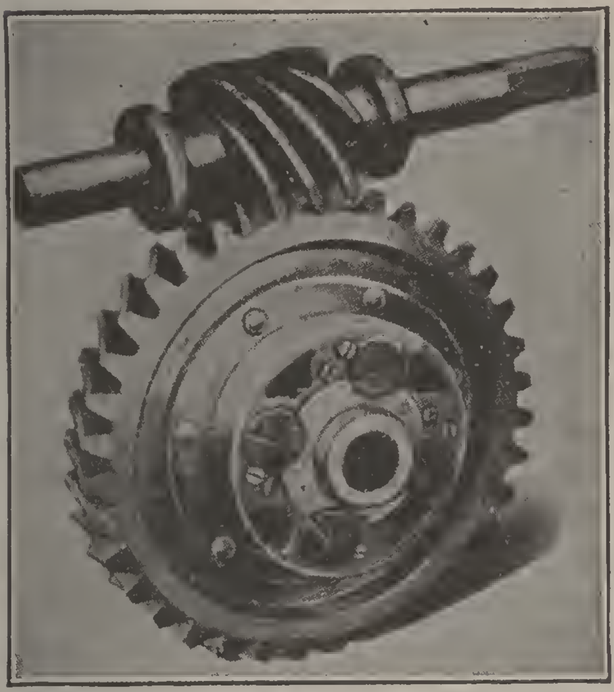

Fig. 87. Final Drive on Light Truck

For 1916, the very apparent tendency in final drives is toward spiral bevels for pleasure cars and worms for electrics and trucks. The tendency toward spirals is very great, amounting practically to a landslide, 57 per cent using it against 10 for 1915. The development of special machinery for cutting these gears and the understanding of their use has brought this about. In the truck field there has been a similar movement toward the worm, due to similar causes.

FRAME TROUBLES AND REPAIRS

The more usual troubles which the repair man will encounter are sagging in the middle; fracture in the middle at some heavily loaded point or at some unusually large hole or series of holes; twisting or other distortion due to accidents; bending, or fracture

of a sub-frame or cross member; bending or fracture at a point where the frame is turned sharply inward, outward, upward, or downward.

Sagging. A frame sags in the middle for one of two reasons: either the original frame was not strong enough to sustain the load, or the frame was strong enough normally, but an abnormal load was carried which broke it down. Sometimes a frame which was large enough originally, and which has not been overloaded, will fail through crystallization, or in more common terms, fatigue of the steel. This occurs so seldom, and then only on very old frames, that it cannot be classed as a "usual" trouble; moreover, it cannot be fixed.

When a frame sags in the middle, the amount of the sag determines the method of repair. For a moderate sag, say $\frac{1}{4}$ to $\frac{1}{2}$ inch, a good plan is to add truss rods, one on either side. These should be stout bars, well anchored near the ends of the frame and at points where the frame has not been weakened by excessive drilling. They should be given a flattened U-shape, with a couple (or more) uprights down from the frame between them. The material for them should be stiff enough and strong enough to withstand bending, and should be firmly fastened to the underside of the frame. The truss rods should be made in two parts with a turnbuckle to unite them, the ends being threaded right and left to receive the turnbuckle. When truss rods are put on a sagged frame, it should be turned over and loaded on the under side; then the turnbuckles should be pulled up so as to force the middle or sagged part upward a fraction of an inch—say $\frac{1}{8}$ to $\frac{1}{4}$ inch—and then the frame turned back, the other parts added, and the whole returned to use. A job of this kind which takes out the sag so that it does not recur is a job to be proud of.

Fracture. Many a frame breaks because too much metal was drilled out at one place. Fig. 88 shows a case of this kind. The two holes were drilled one above the other for the attachment of some part, and were made too large. They were so large that at this particular point there was not enough metal left to carry the load, and the frame broke, as indicated, between the two holes and also above and below. A break of this kind can be repaired in two good ways. The first and simplest—as well as the least

expensive—is to take a piece of frame 10 to 12 inches long of sufficiently small section to fit tightly inside this one. Drive it into the inside of the main frame at the break, rivet it in place firmly throughout its length, and then drill the desired holes through both thicknesses of metal.

This is not so good as welding. A break of this kind can be taken to a good autogenous welder who will widen out and clean the crack, fill it full of new metal, fuse that into intimate contact with the surrounding metal, and do so neat and clean a piece of work that one would never know it had been broken. When a welding job is done on a break like this, and no metal added besides that needed to fill the crack, subsequent drilling should be at an angle to avoid a repetition of the overloading condition. In the figure, the dotted lines suggest the drilling. By staggering the holes in this way, there is a greater amount of metal to resist breakage than would be the case with one hole above the other—a method which might preferably have been used in the first place.

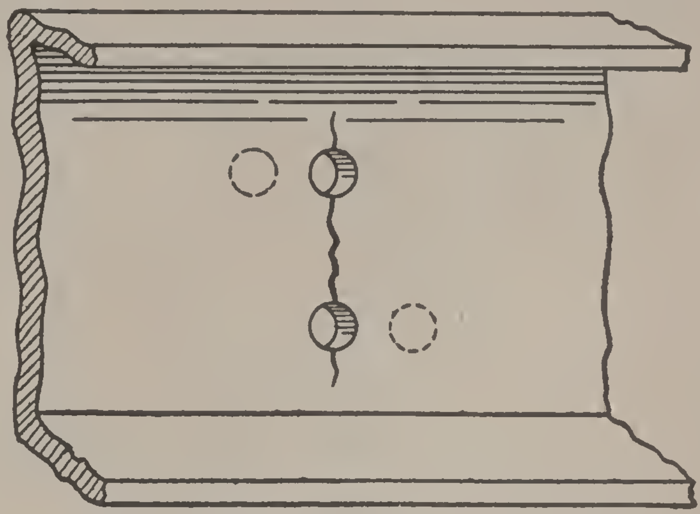

Fig. 88. Reboring Cracked Steel Channel

So much welding is done now, and so many people know of its advantages, that every repair shop of any size should have a welding outfit. A frame job is essentially an inside bench job, but a large number of cases of welding could be done directly on the car outside the building, particularly in summer when the outside air and cooling breezes are desirable. So, it is well to construct a small truck on which to keep the oxygen tank, acetylene cylinder, nozzle for working, and a fire extinguisher. One form of a truck is shown in Fig. 89, this being a simple rectangular platform with casters, a handle, and a rack to hold the tanks. It saves many a step and is particularly convenient in summer months. This outfit is essentially a home-made affair, but the gas-welding and electric-welding manufacturing companies have designed small outfits especially for automobile repair work, which would be

preferable to Fig. 89, especially where the amount of repair work warrants a reasonable expenditure for a welding outfit.

SPRING TROUBLES AND REMEDIES

Usual Spring Troubles. *Lubrication.* The average repair man is apt to have more call to lubricate the leaves of a spring than any other one thing in connection with springs. True, they lose their temper, sag, and show signs of losing their set; plates break in the middle, at the bolt hole, and near the ends of the top plate; and inside plates break in odd places. More frequently, springs make an annoying noise, a perceptible squeak because the plates have become dry and need lubricating. When this happens, and the up or down movement of the car rubs the plates over one another, dry metal is forcibly drawn over other dry metal with which it is held in close contact; naturally, a noise occurs.

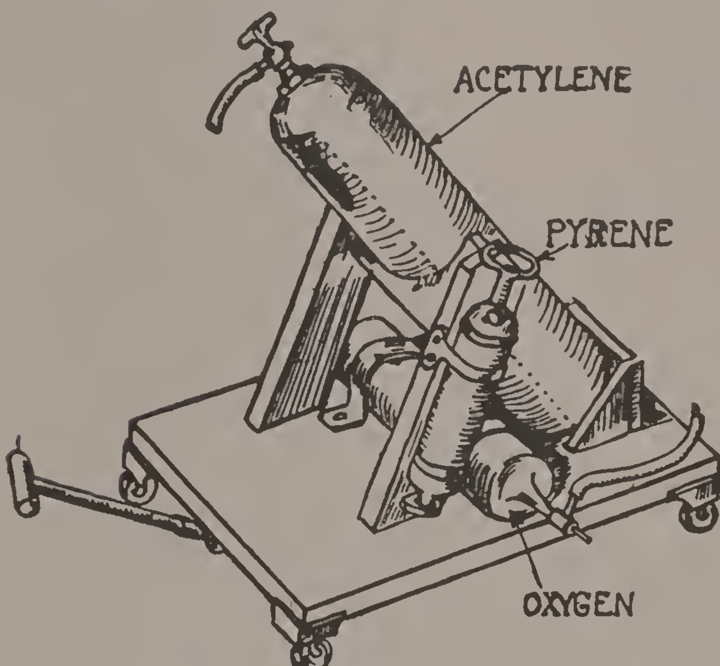

Fig. 89. Handy Oxy-Acetylene Outfit

To take care of this job, it is well to construct a spring leaf spreader. Of course, the job is best done by jacking up the frame, dismounting the spring entirely, taking it apart and greasing each side of each plate thoroughly with a good graphite grease, then reassembling, and putting back under the car. This is the best way, but it costs the most and few people will have it done. Sometimes spring inserts are used; these are thin sheets of metal of the width and length of the spring plates, having holes filled with lubricant over which is a porous membrane.

For the ordinary spreading job, the plates must be pried apart and the grease inserted with a thin blade of steel, for instance, a long-bladed knife. To spread the leaves, jack up the frame so as to take off the load, then insert a thin point and force it between a pair of leaves. In Fig. 90, two forms of tools for doing this forcible separation are shown. The first is a solid one-piece forging with the edges hardened. It is used by sliding the edges over the ends

of the spring leaf, then giving it a twist to force it in between them, as shown in the figures. The second tool is intended to be forced between two plates by drawing back on the handle.

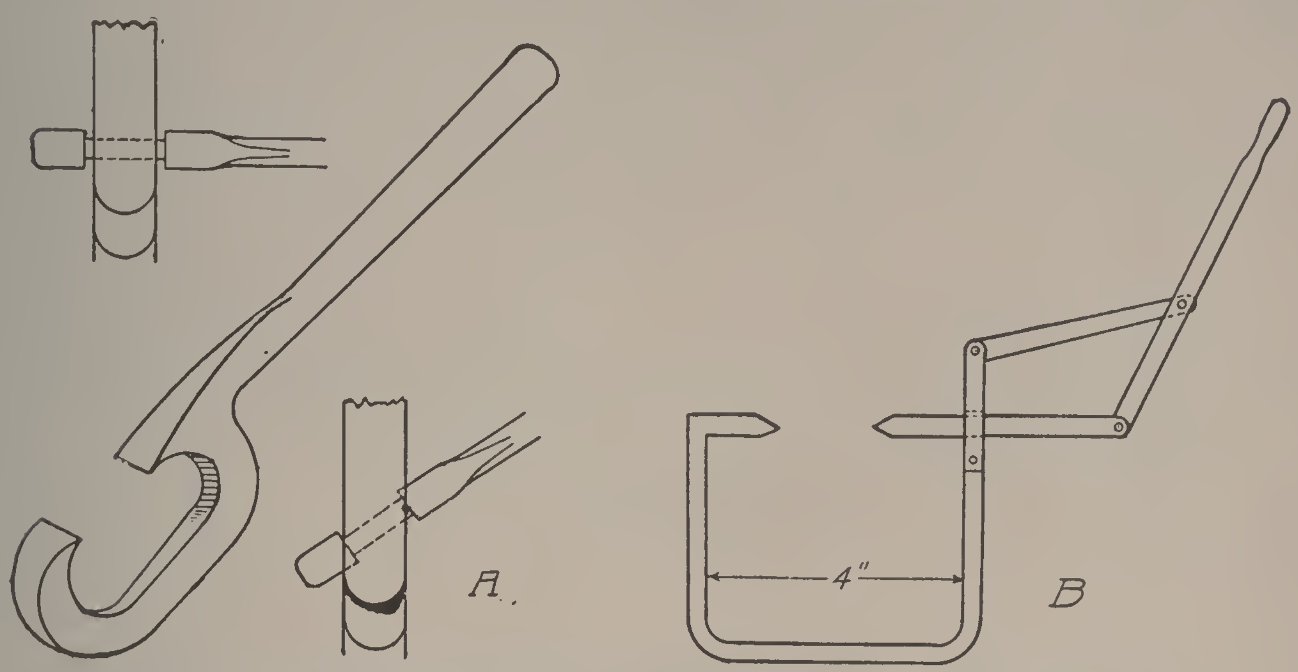

Fig. 90. Handy Tools for Spreading Spring Leaves to Insert Lubricant

Tempering or Resetting Springs. When springs lose their temper or require resetting, it is better for the average repair man to take them to a spring maker; this is a difficult job, requiring more than ordinary knowledge of springs, their manufacture, hardening, annealing, etc. When springs are in this condition, they

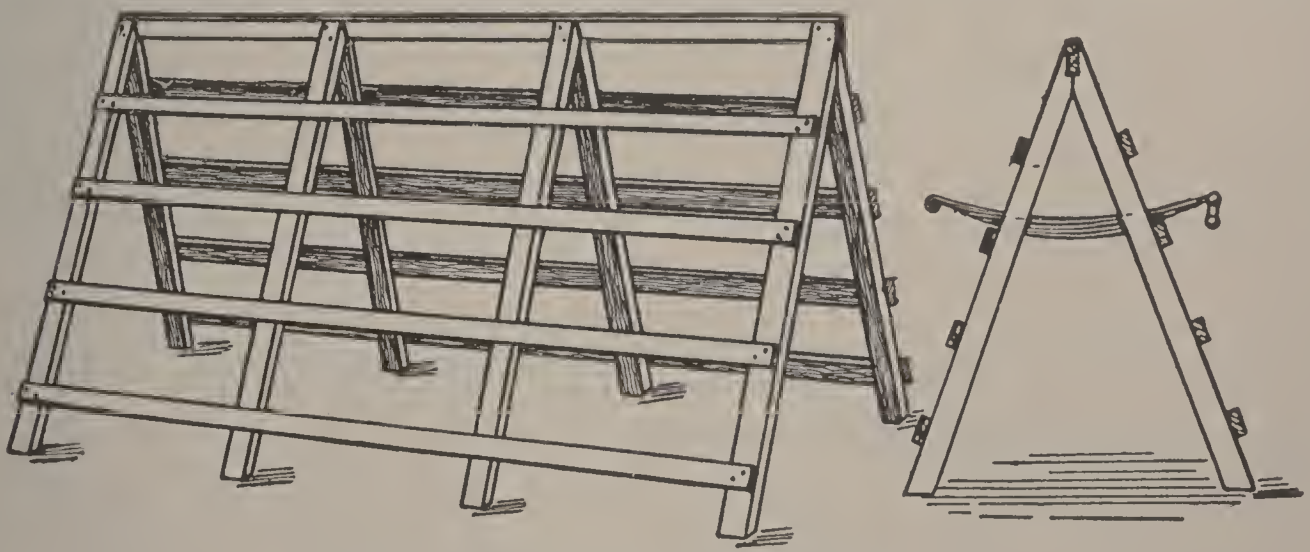

Fig. 91. Simple and Well-Designed Spring Rack

sag down under load and have no resiliency. If a great many springs are handled, a rack like that shown in Fig. 91 is well worth making.

Broken Springs. When springs break, there is but one shop remedy, a new plate or plates. But when they break on the road, it is necessary to get home. When the top plate breaks near the

shackled end, repair this sufficiently to get home by using a flat wide bar with a hole in one end big enough to take the shackle bolt; bolt this to the spring in place of the end of the leaf which is broken.

FRONT AXLE TROUBLES AND REPAIRS

Alignment of Front Wheels Troublesome. The lack of alignment of front wheels gives as much trouble as anything else in the

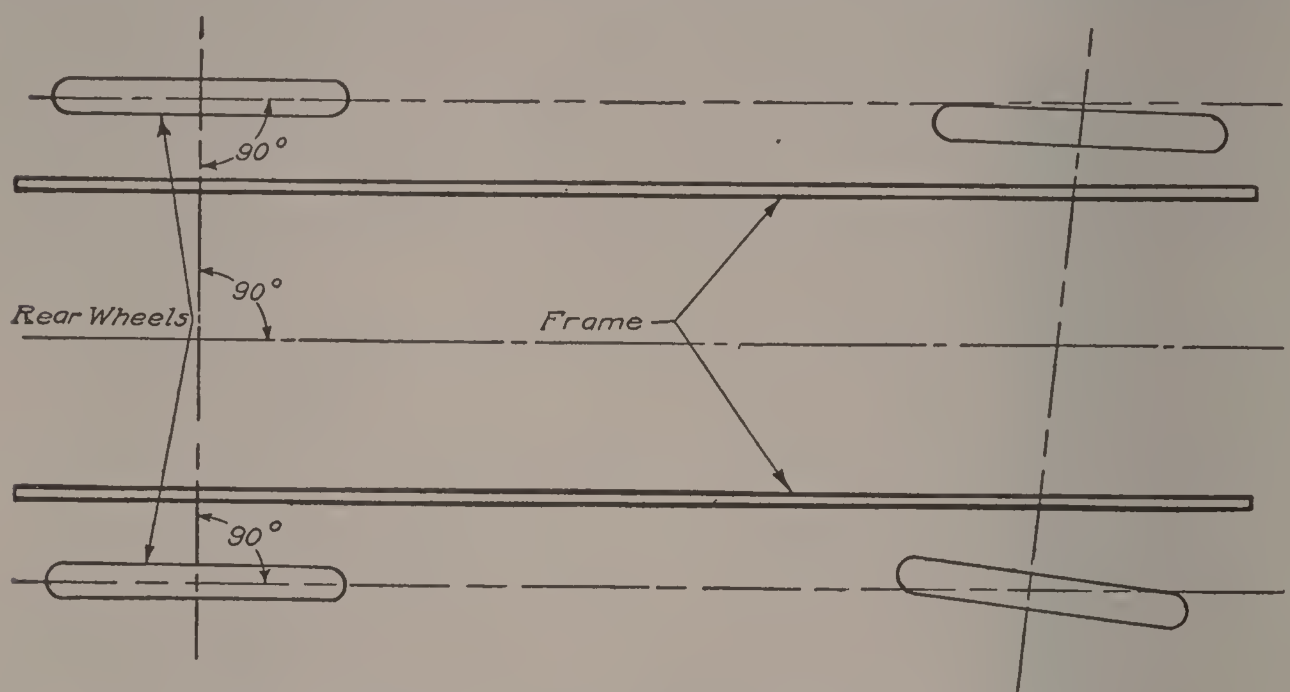

Fig. 92. Diagram Showing Front Axle and Wheels Out of True

front unit. This lack not only makes steering difficult, inaccurate, and uncertain, but it also influences tire wear to a tremendous extent. As Fig. 92 indicates, even if the rear axle should be true with the frame, at right angles to the driving shaft, and correctly placed crosswise—that is, correct in every particular with the shafts both straight so that the wheels must run true—the fronts may be out

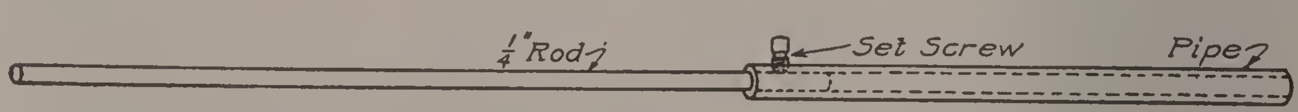

Fig. 93. Simple Measuring Rods for Truing-Up Wheels

with the frame, out of track with the rears, or out with respect to one another.

Now in order to know about the front wheels, they should be measured, and while this sounds simple, it is anything but that. In the first place there is little to measure from, or with. A good starting place is the tires, and a simple measuring instrument is the one shown in Fig. 93. This consists of a rod about $\frac{1}{4}$ inch in diameter and about three feet long, fitted into a piece of pipe about two feet

long, with a square outer end on each and a set screw to hold the measurements as obtained. By placing this between the opposite sides of the front tires, it can be ascertained whether these are parallel, and whether they converge or diverge toward the front. But

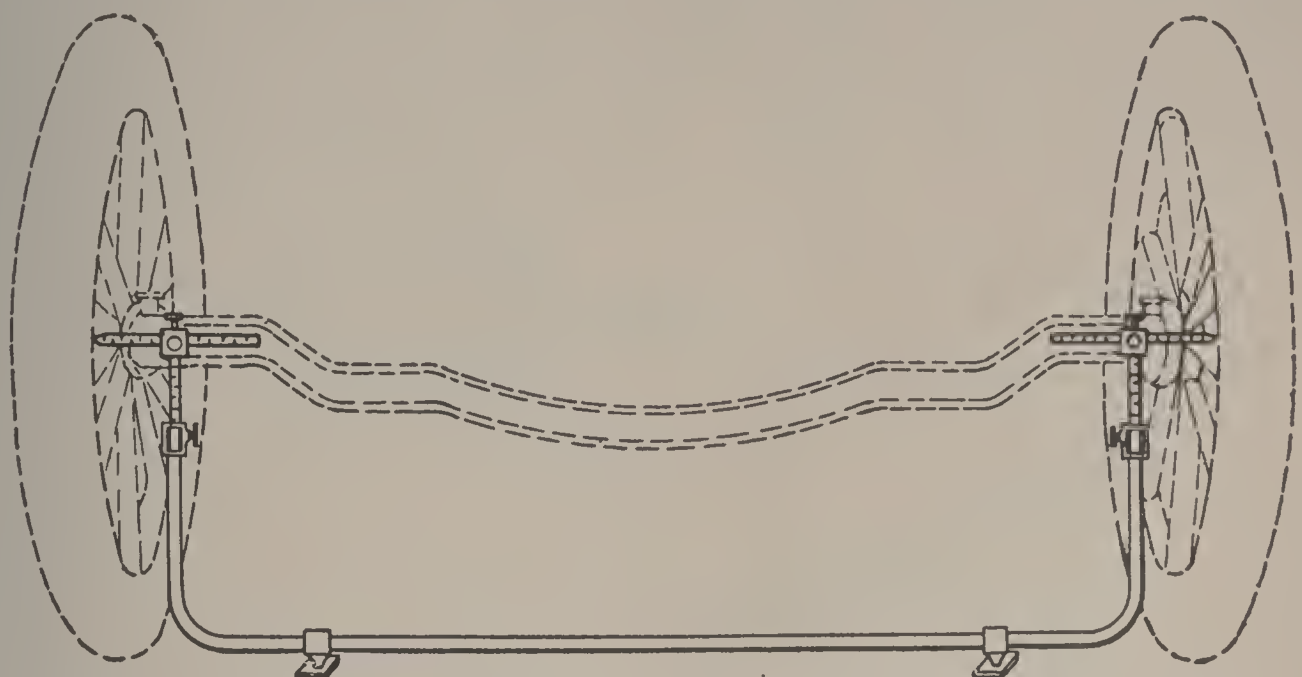

Fig. 94. Accurate Measuring Rod for Truing-Up Wheels. Better Design than Fig. 93

knowing this, the driver or repair man is little better off than before, because this may or may not be the practice of the makers of the car, and it may or may not cause the trouble.

In short, a more accurate and more thorough measuring instrument is needed, Fig. 94. Such a one can be bought, but a similar outfit can be made from $\frac{3}{8}$-inch bar stock, using thumb nuts where the two uprights join the base part, and also at the two points, or scribers, on these uprights. Having the floor to work from, the

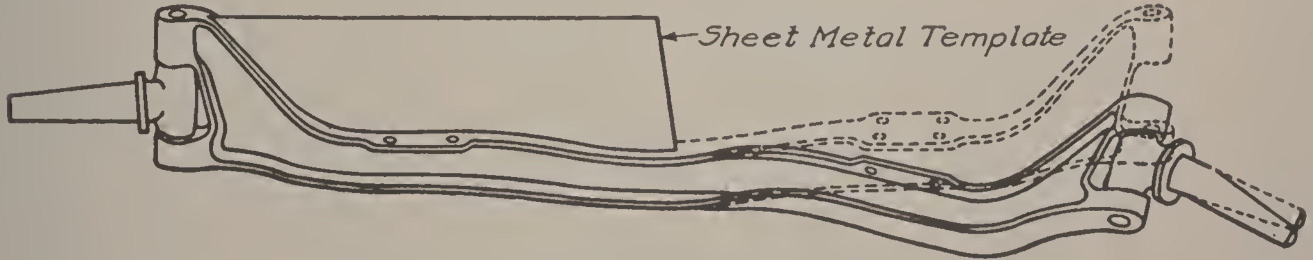

Fig. 95. Template for Showing if Axle Is Bent

heights can be measured, and thus the distance between tires may be taken on equal levels. Thus, a bent steering knuckle can be detected with this apparatus. Similarly, the center line and frame lines of the car can be projected to the floor, and by means of the instrument, it can be determined whether the axle is at a perfect right angle with these, and whether the wheels are perfectly parallel. Given the

frame line, too, it can be determined whether the wheels track with one another.

Straightening an Axle. When an axle is bent, as in a collision, a template is useful in straightening it. This can be cut from a thin sheet of metal, light board, or heavy cardboard. It is an approximation at best and should be used with great care. Fig. 95 shows such a template applied to an axle which needs straightening.

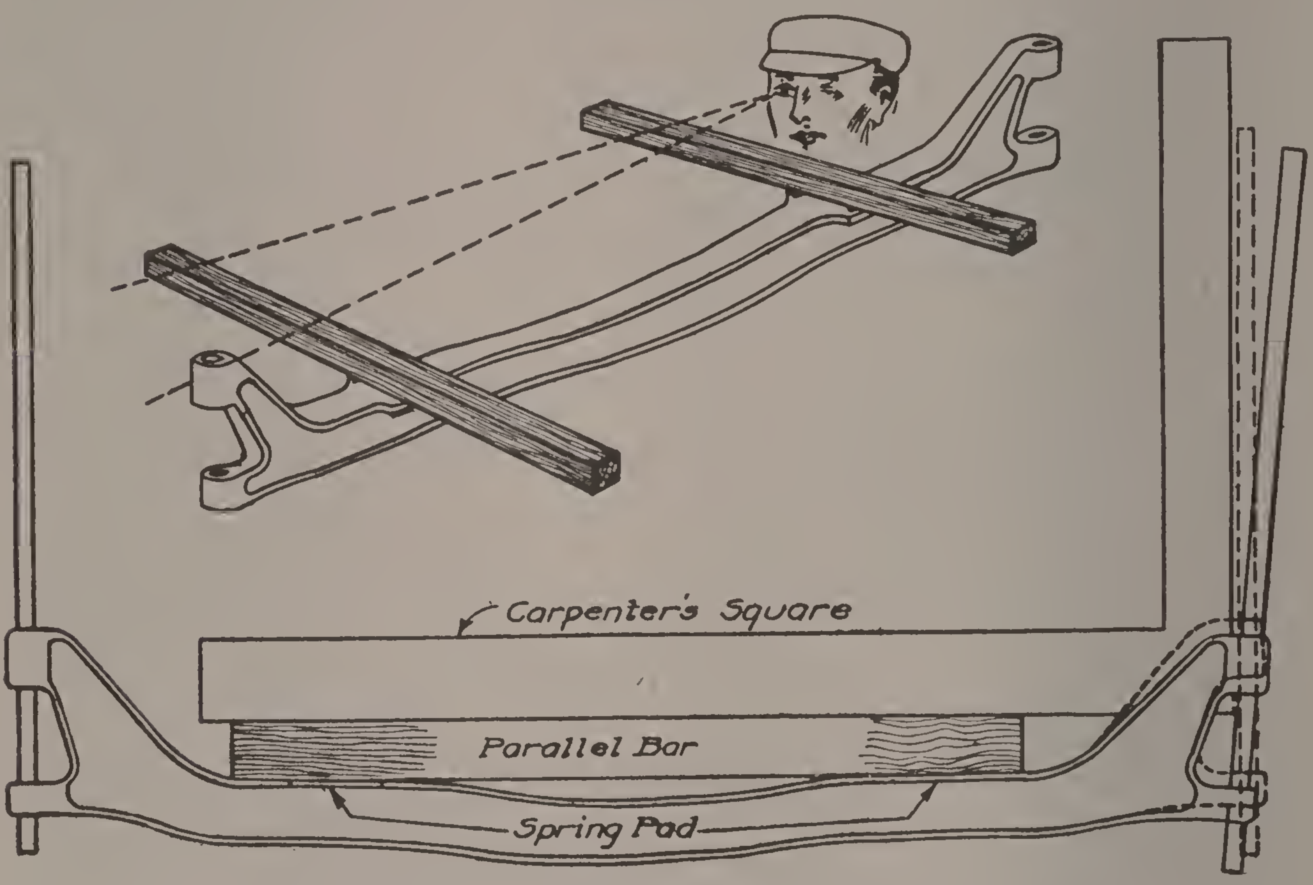

Fig. 96. Diagram Illustrating Method of Truing-Up an Axle

When the axle is bent back to its original position, a pair of straight edges laid on top of the spring pads will be of great assistance in getting the springs parallel, as the worker can look across the straight edges with considerable accuracy. This is indicated in the first part of Fig. 96 which shows the general scheme. It shows also how the axle ends are aligned, using a large square on top of a parallel bar, but of course this cannot be done until the last thing, at least not until the spring pads are made parallel.

REAR-AXLE TROUBLES AND REPAIRS

Jacking Up Troubles. Much rear-axle work—practically all, in fact—calls for the use of the jack. True, the full-floating type of axle can have its shaft removed without jacking, but aside from differential removal there is little rear-axle trouble in which it is

necessary to remove the shaft alone. In almost all cases, the axle must be jacked up. Many axles have a truss rod under the center and this is in the way when jacking; however, this can be overcome. Make from heavy bar iron a U-shaped piece like that shown in Fig. 97, on top of the jack, making the width of the slot just enough to admit the truss rod. The height, too, should be as little as will give contact with the under-side of the axle housing.

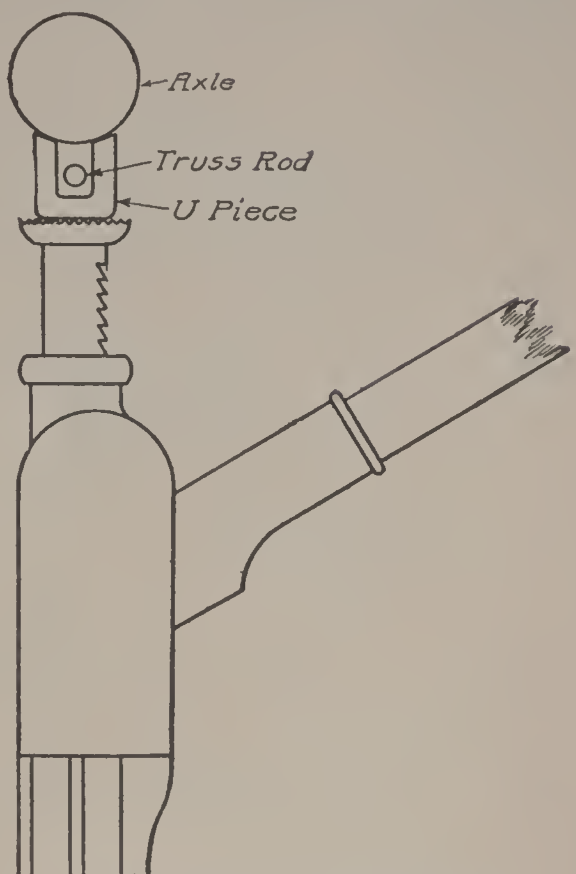

Fig. 97. Simple Arrangement for Avoiding Rear-Axle Truss Rod

Substitute for Jack. A good substitute for a jack is a form of hoist, Fig. 98, which will pick up the whole rear end of the car at once. This not only saves time and work, but holds the car level while jacking one wheel does not. Moreover, with a rig of this kind the car can be lifted so easily and high that it is easy to work under. The usual hoisting blocks are very expensive, but this hoist can be easily made by the ingenious repair man. This is made from an old whiffletree, to the ends of which are attached a pair of chains. For the lower ends of the chains, a pair of hooks are made sufficiently large to hook under and around the biggest frame to be handled; with the center of the whiffletree fastened to the hook of a block and tackle, the hoist is complete. By slinging the hooks under the side members of the frame at the rear, it is an easy matter to quickly lift that end of the chassis any distance desired.

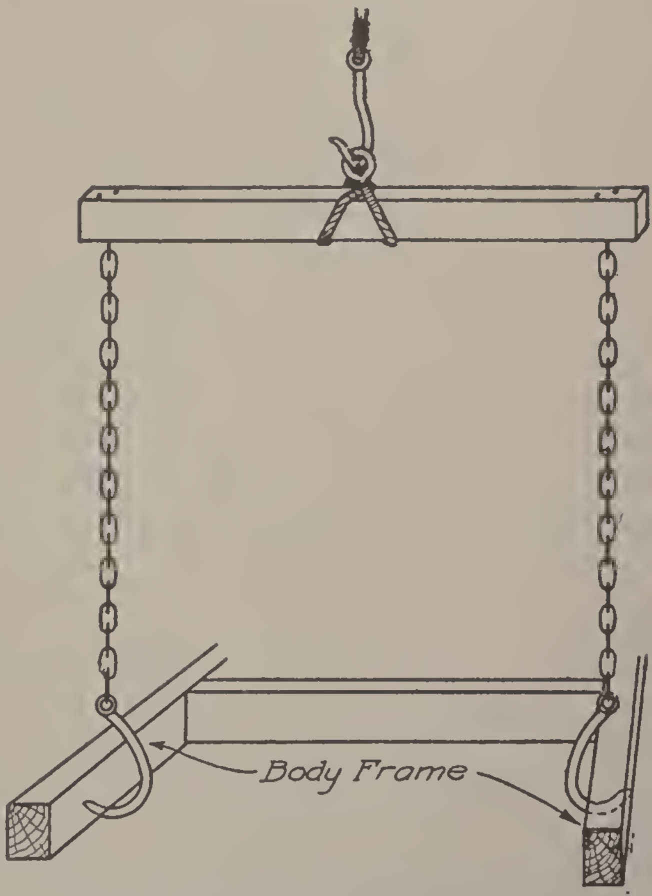

Fig. 98. Simple Automobile Frame Hoist

Workstand Equipment. Next to raising the rear axle, the most important thing is to support it in its elevated position. To leave it on jacks is not satisfactory, for they will not raise the frame high enough, and furthermore, they are shaky and may easily let the whole rear end fall over, doing considerable damage. With the overhead hoist, the chains or ropes are in the way. So a stand is both a necessity and a convenience. In Fig. 99 several types are shown. *A* is essentially a workstand, intended to hold the axle and part of the propeller shaft while doing repair work thereon. It consists of a floor unit or base, built in the form of an A, with six uprights let into it, preferably mortised and tenoned for greater

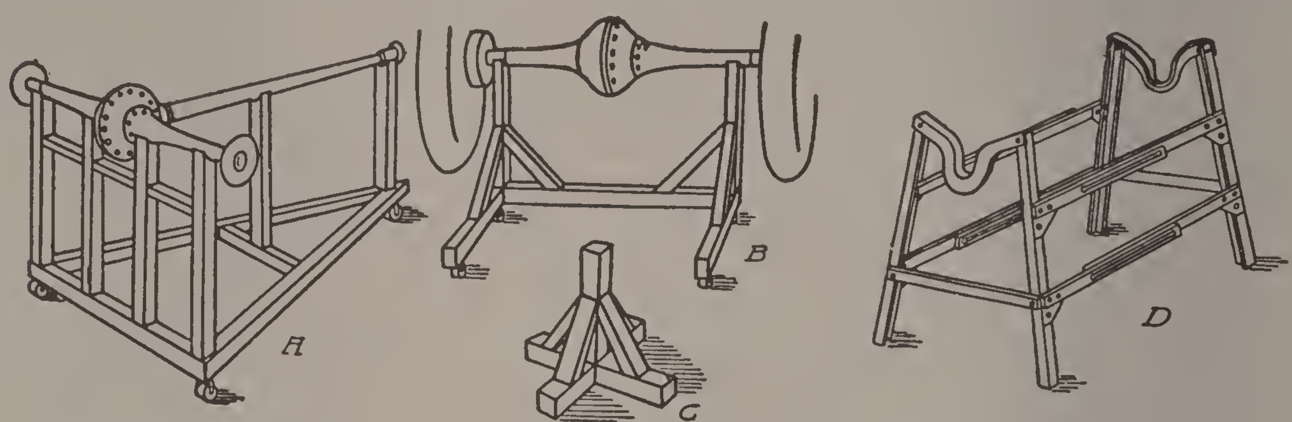

Fig. 99. Types of Handy Stands for Rear-Axle Repair Work

strength and stiffness. Then, the four rear uprights are joined together for additional stiffness and rigidity. If casters are added on the ends it can be more conveniently handled around the shop.

The forms *B* are for more temporary work and consequently need not be so well or so elaborately made. The little stand *C* is a very handy type for all-around work. Stands of this kind, with the top surface grooved for the axle, are excellent to place under cars which have been put in storage for the winter.

The stand *D* is, like *A*, a workstand pure and simple. In this however, the dropped end members allow supporting the axle at those points, while the elimination of central supports gives plenty of room for truss rods. This type of stand would preferably be made from metal, pressed steel or small angle irons being very good. Every repair shop should have a considerable number and variety of stands, made as the work demands them, and made just to fit this particular class of work.

Locating Trouble. Many times, a car may be brought in for rear axle repair on which the repair man cannot find any trouble,

Many an axle often develops an elusive hum, or grinding noise, which not only defies location, but is not continuous. The writer had such a one at one time, and was sure that the bevel gears were out of alignment and were cutting one another. It was a low pitched whine which was not apparent at low speeds, but began to be heard around 18 to 20 miles an hour, and at times was very apparent. The noise was very annoying, but tearing down the rear construction showed absolutely no trouble so the noise could not be at that point. Sometime later the noise was definitely located in a pair of worn speedometer gears on the right end of the front axle. That is, the supposed rear axle trouble was not on the rear axle at all.

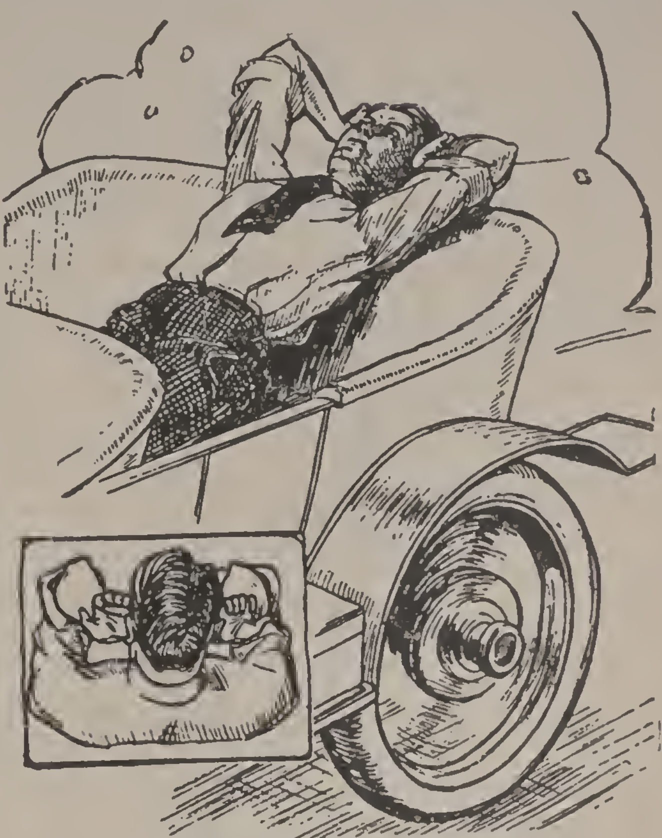

Fig. 100. Listening for Rear-Axle Noises

A good way to listen to rear axle hums out on the road is to lay back over the rear end of the car, Fig. 100, with the head against the top of the seat and projecting over slightly, and with the hands cupped in *front* of the ears, so as to catch every noise that arises. The larger sketch shows the general scheme, the small inset giving the method of holding the hands. When the sound arising from the axle is a steady hum, the gears are in good condition and well adjusted. If this sound is interrupted occasionally by a sharper, harsher note, it may be assumed that there is a point in one of the gears or on one of the shafts where things are not as they should be. By trying the car at starting,

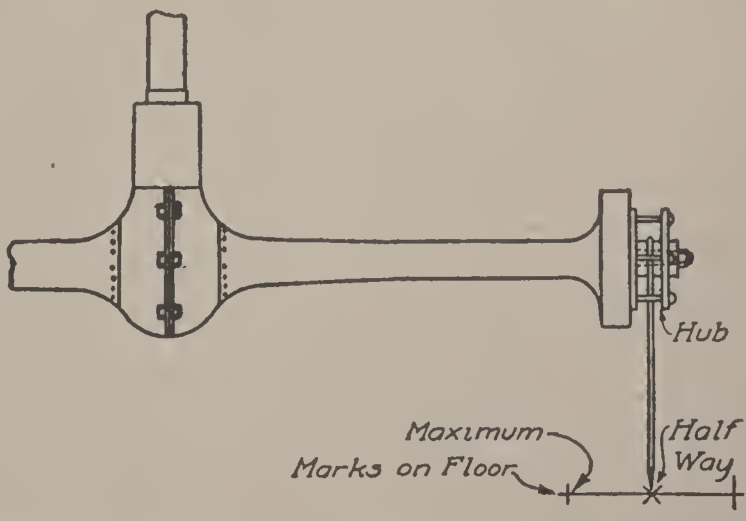

Fig. 101. Diagram Showing Method of Checking-Up Ford Axles

slowing down, running at various speeds, and coasting, this noise can be tied to something more definite, some fixed method of happening. In advance of actual repair work, including tearing down the whole axle, the gears can be adjusted. This can generally be done from outside the axle casing and without a great deal of work. If the adjustment makes matters worse, it can be reversed, or if it improves the situation, the adjusting can be continued, a little at a time, until the noise gradually disappears.

Checking-Up Ford Axles. Many cases of bent Ford rear axles can be fixed without taking down the whole construction. The principal point is to find out how much and which way the axle is bent. By removing the wheel on the bent side, and placing on the axle end the rig shown in Fig. 101, the extent of the trouble can be indicated by the axle itself. The rod is a long, stiff, iron one, fastened permanently to an old Ford hub, with its outer end pointed. The rig is placed on the axle and held by the axle nut, but without the key, as the axle must be free to turn inside the hub. With the pointed end of the rod resting on the floor, and with high gear engaged, have some one turn the engine over slowly so as to turn the axle shaft around. As it revolves, the hub will be moved and the pointed end on the floor will indicate the extent of the bend. By marking the two extreme points, and dividing the distance between them, the center is found. Then a rod can be used as a bar to bend the axle until the pointed rod end is exactly on the center mark. A little practice with this rig will enable a workman to straighten out a Ford rear axle in about the time it takes to tell it.

GENERAL INDEX

GENERAL INDEX

In this Index the *Volume number* appears in Roman numerals—thus: I, II, III, IV, etc., and the *Page number* in Arabic numerals—thus: 1, 2, 3, 4, etc. For example: Volume IV, Page 327, is written, IV, 327.

The page numbers of this volume will be found at the bottom of the pages; the numbers at the top refer only to the section.

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